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Potential Habitat of Acropora spp. on Florida Reefs

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Potential Habitat of *Acropora* spp. on Florida Reefs

by

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A thesis submitted in partial fulfillment
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Master of Science
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DEDICATION

To the man who never asks for credit,

but often deserves the most.

Thank you, Dad.

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Last but not least, I would like to thank my family and friends for their unyielding support throughout my academic career. I owe my deepest gratitude to my father who has provided me the love, support and guidance throughout my life, without which I would not be where I am today.

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ABSTRACT

Elkhorn and Staghorn corals (*Acropora palmata, A. cervicornis*) were listed as threatened species under the Endangered Species Act (ESA) in 2005. The threatened status of these species is unprecedented given the vital role they historically played as major constructors of western Atlantic and Caribbean coral reefs. The goal of my study was to evaluate the current extent of habitat of the two species using a database of reported *in situ* observations. From these observations, potential habitat maps were produced based on benthic substrata and depth parameters throughout the Florida reef tract using GIS software. Locations of 99% of *A. palmata* observations and 84% of *A. cervicornis* observations coincided with previously mapped reef or hardbottom habitat. These results indicate that potential habitat for *A. palmata* is currently well defined and that potential habitat for *A. cervicornis* is more variable than that for *A. palmata.*

This study provides a starting point in the creation of a revised critical habitat delineation for *Acropora* spp. in Florida. Using the mapped reef and hardbottom classifications throughout the Florida reef tract, probable habitat maps were generated using buffers that incorporated 95% and 99% of reported observations of colonies of *Acropora* spp. One of the most important differences between the previously generated critical habitat map and the new probable

habitat map is observed in the southeast Florida region, where probable habitat extends further north than critical habitat and, thus, encompasses additional habitat for *A. cervicornis* and potentially *A. palmata*.

INTRODUCTION

Corals of the genus *Acropora* have commonly epitomized coral reefs worldwide because of their typically shallow distributions (i.e., accessibility) and characteristic branching or bushy morphologies. Two distinct species occur in the western Atlantic and Caribbean region, *Acropora cervicornis* (Lamarck 1816) and *A. palmata* (Lamarck 1816). A third form, commonly known as *A. prolifera* (Lamarck 1816), is now recognized to be a hybrid between *A. cervicornis* and *A. palmata* (Van Oppen et al. 2000; Vollmer and Palumbi 2002).

According to Veron (2000), *A. cervicornis* is characterized as arborescent with cylindrical branches that subdivide infrequently, thus its common name, Staghorn coral. Historically this species was common on upper to mid-reef slopes and in lagoons with clear waters. According to Veron (2000), *A. palmata* is characterized by parallel, obliquely inclined, very thick tapered branches thus its common name, Elkhorn coral. This species was historically common and conspicuous on shallow outer reef margins exposed to wave action.

The habitat of *A. palmata* has been so well defined that its distribution has been used to interpret both modern environments and paleoenvironments. Hubbard (1989; 1997) used the occurrence and morphologies of *A. palmata* as an indicator of wave and storm prevalence on reefs. Because this species is adapted to high light intensities and, therefore, water depths typically less than

10 m, its fossil distribution has been widely used to interpret rates of sea level rise (Blanchon and Shaw 1995; Toscano and Lundberg 1998; Blanchon and Eisenhauer 2001; Toscano and Macintyre 2003; Brock et al. 2008; Gabriel et al. 2009; Blanchon 2010).

The precipitous decline of *Acropora* spp. in the western Atlantic and Caribbean is a major issue in discussions of coral-reef conservation. Their designation as candidate species for listing as threatened under the US Endangered Species Act (ESA) in 1999 (Diaz-Soltero 1999) and finally the formal listing as threatened in 2005 (*Acropora* Biological Review Team 2005) highlighted the concern for these historically major reef-building corals, bringing attention to the overall decline in reef-building corals over the past several decades.

Recent History of Acropora Decline

Disturbance events, particularly exceptionally strong winter cold fronts and hurricanes that caused extensive mortality in *Acropora* spp., were recognized by researchers in the Dry Tortugas in the late 19th and early 20th centuries (Wells 1932; Jaap et al. 2008). The shallow habitats and branching morphologies of *Acropora* spp. made them particularly vulnerable to disturbance events, while their rapid growth rates and branching structures enabled populations to recover from such disturbances in a few years to decades (Gladfelter et al. 1978; Jaap et al. 1988). Thus, the cold-water event in January 1978 that resulted in extensive mortality of *Acropora* spp. in the Dry Tortugas and elsewhere along the Florida reef tract was notable, but not of major concern (Davis 1982; Porter et al. 1982; Roberts et al. 1982). Similarly, Jaap (1979) noted bleaching on Middle Sambo Reef in 1973 and concluded that bleaching events of short duration have limited long-term effect on reef communities.

Unfortunately for the Florida reef communities, the cold-water event of 1978 was followed by the spread of white-band disease through *Acropora* populations (Gladfelter 1982). In addition, increasingly frequent disturbances have limited the recovery of extensive *Acropora* thickets in most parts of the Florida reef tract. These disturbances included widespread mass-bleaching events in 1983 (Jaap 1985) and 1987 (Lang et al. 1992), an exceptionally severe bleaching event in 1998 (Hoegh-Guldberg 1999), and the region-wide *Diadema* die off, also in 1983 (Lessios 1988). Bleaching was also observed in the Florida Keys in 1989, 1990, and 1991. Porter and Meier (1992) reported declines in live coral cover of up to 44% between 1982 and 1991 at several locations along the Florida reef tract. Somerfield et al. (2008) also noted declines in number of species, as well as coral cover on shallow and deep offshore reefs, following the bleaching event of 1998. The Coral Reef Evaluation and Monitoring Program (CREMP), which began annual assessments at 40 sites Keys wide in 1996, documented subsequent decline, such that by 2006, live coral cover averaged 6-7% (Callahan et al. 2007). A chronological summary of historical observations and disturbance events is presented in Table 1.

Thus, the two western Atlantic and Caribbean species of *Acropora* have been declining in abundance for the past 30-plus years, throughout the Florida

Keys (Jaap et al. 1988; Porter and Meier 1992) and Caribbean (Aronson and Precht 2001b). For example, a study by Miller et al. (2002) estimated a 93% decline of *A. palmata* and a 98% decline of *A. cervicornis* between 1983 and 2000 at Looe Key National Marine Sanctuary in the Florida Keys. Miller et al. (2002) attributed decline to a wide range of factors, including, but not limited to, storms, disease, high-temperature events that caused mass bleaching, water quality decline, and ship groundings. Physical damage to these corals by anchor deployment (Halas 1985), boat grounding, diver disturbance, fishing lines, hooks, lobster pots, and buoys (Jaap et al. 1984) also have been commonly observed throughout the Florida Keys.

Single events can result in multiple stressors on a coral community. For example, in 1980 Hurricane Allen caused considerable physical damage to both *A. palmata* and *A. cervicornis* populations in Jamaica. In addition to the physical damage, corallivores out-survived their prey, which reduced the ability of the corals to recover (Hughes and Connell 1999). Signs of recovery were not apparent in the Caribbean throughout the 1980s and for a major part of the 1990s. Recovery has been observed in some areas in the late 1990s and into the early 2000s, but has been slow or unobserved in others (Grober-Dunsmore et al. 2006).

Human population increases in southeast Florida pose a variety of threats to coral reef ecosystems, including nutrient enrichment, diminished water transparency, phosphate inhibition of calcification, biotic replacement, and increased bioerosion (Simkiss 1964; Weiss and Goddard 1977; Smith et al.

1981; Hallock and Schlager 1986). In spite of these anthropogenic influences, thickets of *A. cervicornis* have been found off the highly populated southeast coast of Florida. Significant populations have been reported in shallow nearshore water off Fort Lauderdale (Thomas et al. 2000), where they are thriving at or near the latitudinal limits for the species. The size of these thickets were found to range between 1,000 and 8,000 m^2, with *A. cervicornis* representing 87-97% of all scleractinians (Vargas-Angel et al. 2003). These patches of *A. cervicornis* were found to be fertile and spawned each summer (Vargas-Angel et al. 2006). These populations are believed to be the largest and northernmost in the continental USA and are a potential source of propagules to repopulate or replenish threatened populations in south Florida habitats (Vargas-Angel and Thomas 2002).

In addition to anthropogenic-induced disturbances, these south Florida populations are also exposed to natural threats, such as white-band disease, predation, and thermal stress. White-band disease was found on many thickets off Broward County in 2002, as was predation by *Hermodice carunculata,* a corallivorous worm (Vargas-Angel et al. 2003). Surface-water temperatures range from 22-25 °C in the winter (Vargas-Angel et al. 2003), which falls below the optimal temperatures for *Acropora* spp. of between 25°C and 29°C (Jaap et al. 1989). A series of hurricanes including Floyd, 1987; Andrew, 1992; Irene, 1999; Frances, 2004; and Katrina and Wilma in 2005 also have affected the southeast coast of Florida.

Extensive populations of *A. palmata* are notably absent from southeast Florida habitats, although isolated colonies have been found (Banks et al. 2008). Unfortunately for these populations, the northern reefs of the Florida reef tract receive considerably less management than reefs in the Florida Keys and Dry Tortugas (Causey et al. 2002).

The isolated, atoll-like reef system at the terminus of the Florida Keys, the Dry Tortugas, has the longest history of scientific investigations. Research in the Dry Tortugas began in 1881, when Alexander Agassiz mapped the benthos (Davis 1982). Reef research continued with the establishment of the Carnegie Institute Tortugas Laboratory on Loggerhead Key in 1905 (Davis 1982; Shinn and Jaap 2005). Although the original habitat map by Agassiz showed 44 hectares of *A. palmata*, a study by Davis (1982) found that by 1976 *A. palmata* colonies had been reduced to two small patches that occupied a total of less than 600 m^2, as well as a swatch of algal-covered *A. palmata* rubble on the reef crest. This same study found extensive stands of *A. cervicornis* covering a total of 4,780,000 m^2, accounting for 55% of the total scleractinian coral cover. Unfortunately, in January 1977 a severe cold front with water temperatures of 14°C to 16°C wiped out many of these *A. cervicornis* colonies in the Dry Tortugas and impacted the few remaining *A. palmata* colonies (Davis 1982; Porter et al. 1982; Jaap et al. 1989).

Populations of these species in the Dry Tortugas have not recovered to pre-1970's abundances and continued decline was documented at White Shoal from 1999 to 2005, as a result of bleaching and disease (Beaver et al. 2005).

Jaap and Sargent (1994) speculated that populations of *A. palmata* in the Dry Tortugas have not recovered to original levels, due to loss of environmental conditions favorable for recruitment and growth. In 2007, the U.S. National Park Service (NPS) designated a “no-take” Research Natural Area (RNA) around the Dry Tortugas in hopes of protecting this unique region of the Florida reef tract. Kuffner et al. (2008) concluded that it was too early to speculate whether this RNA will would contribute to the restoration of the benthic community in Dry Tortugas National Park.

Characteristics and Importance of Acropora

The fast growth and calcification rates and their branching morphologies are attributes that make *A. cervicornis* and *A. palmata* important to reef communities (Gladfelter et al. 1978). *Acropora palmata and A. cervicornis* have the fastest growth and calcification rates of any species in the Caribbean (Dullo 2005; Figure 1). Historically, *A. palmata* was the major reef-builder in the shallow forereef zones in the Florida reef tract (Shinn et al., 1989; Shinn, 2004) and the extensive three-dimensional structure of *Acropora* thickets provided habitat for many reef fish (Gladfelter et al. 1978; Lirman 1999). *Acropora cervicornis* also played a major role in the structure and ecology of many Caribbean reefs, by contributing significantly to reef accretion, framework construction, and habitat formation (Aronson and Precht 2001a). The precipitous decline of these species has resulted in both decline in reef accretion and loss of habitat for many reef constituents (Jackson 1992; Hughes 1994; Bak and Nieuwland 1995; Jackson et al. 2001).

Historically, *Acropora* populations dominated many reefs of the western Atlantic and Caribbean. Stands of *Acropora* have been dominant features of Caribbean reefs for at least the last 500,000 years according to Pandolfi (2002; Figure 2). Often, the loss of the major stands of *Acropora* has been interpreted to be the result of the combination of disease, siltation, eutrophication, and hurricanes (Norstrom et al. 2009). Others have attributed the decline to the mass mortality of *Diadema antillarum* in the 1980s (Pandolfi 2002). Yet other studies suggest regional decline of *A. palmata* and *A. cervicornis* is due to white-band disease breakouts (Aronson and Precht 2001b). Most likely, the combination of all of these influences has contributed to the continuing decline of not only *Acropora* spp, but general coral cover throughout the Atlantic and Caribbean.

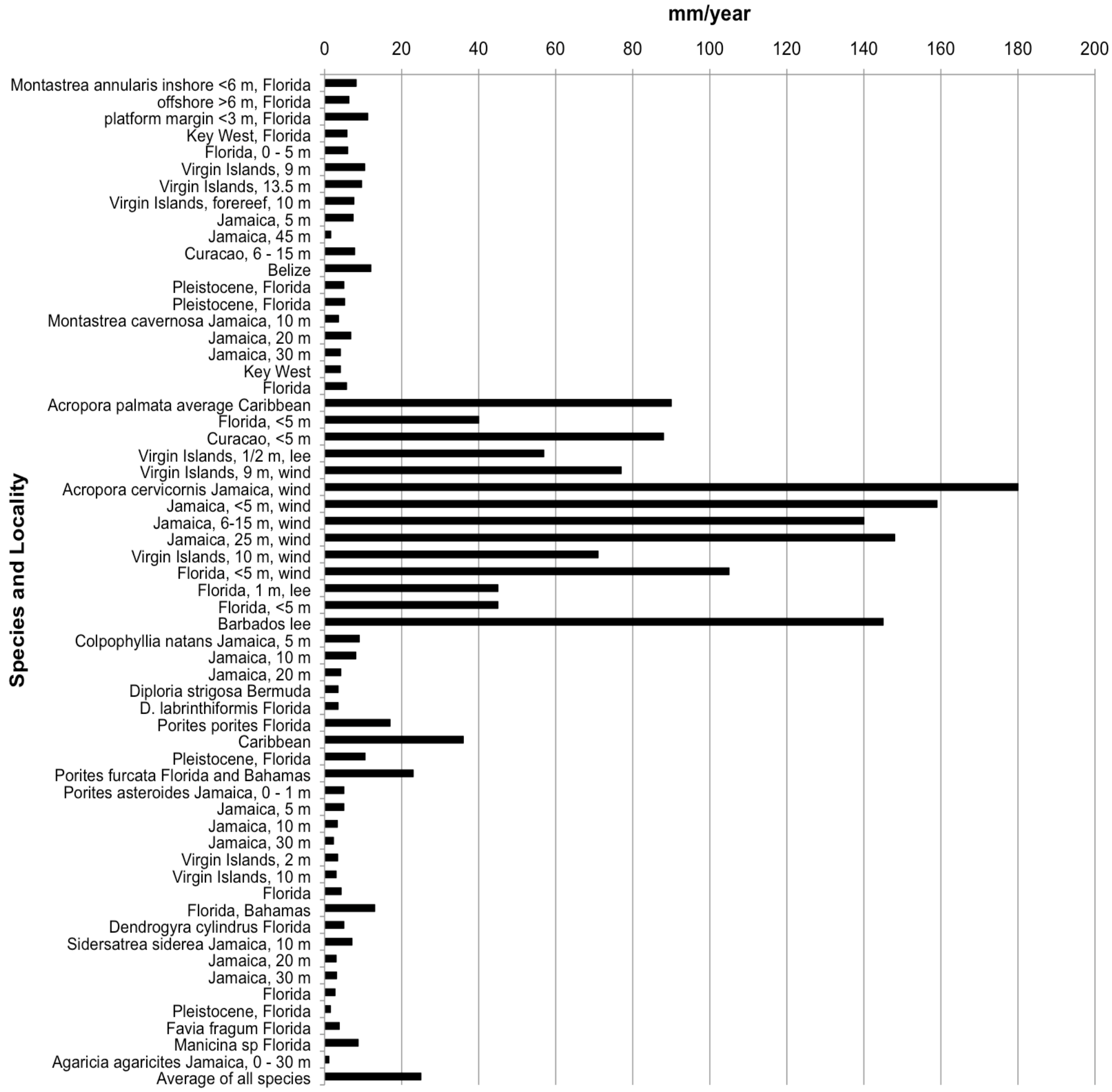


Figure 1: Growth rates of selected zooxanthellate scleractinian corals from the Caribbean region. (Redrawn from Dullo 2005)

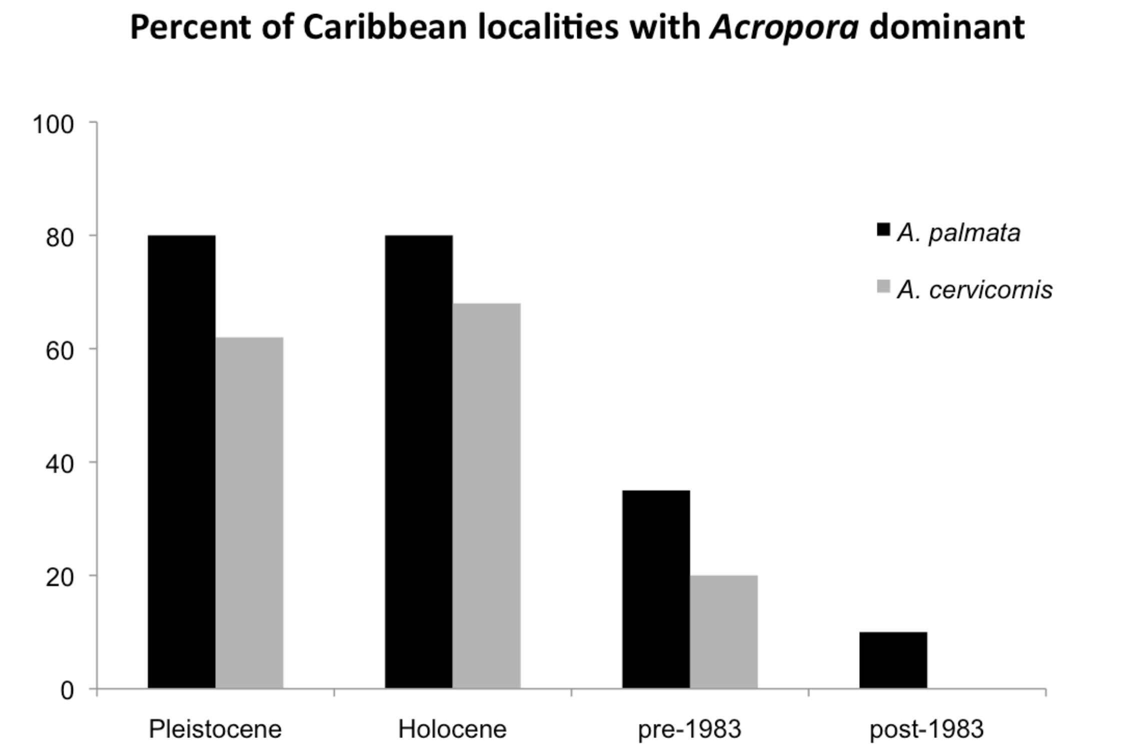


Figure 2: Percent of Caribbean localities with *A. palmata* and *A. cervicornis* as the dominant coral in the Late Pleistocene, Holocene, before 1983 and after 1983. (Redrawn from Pandolfi 2002)

Habitat Requirements of Atlantic and Caribbean Acropora spp.

The specific habitat requirements for these two species are relatively well known. *Acropora palmata* has fairly sensitive environmental requirements including clear, normal marine salinity, well-circulated water; solid substrate; and moderate water temperatures [optimally 25°C to 29°C, without extreme seasonal variation (Jaap et al. 1989)]. During times of high abundance, both *A. palmata* and *A. cervicornis* were common in forereef zones. Prior to the 1970s, *A. palmata* was the dominant coral in wave-exposed and high-surge reef zones, typically at depths less than 10 m, throughout much of the Caribbean (Adey and Burke 1976). *Acropora cervicornis* was found at shallow to medium depths, as deep as 30 m, in brightly lit areas (Fenner 1988). *Acropora cervicornis* thickets in shallow backreef flats and patch reefs were common prior to the 1980s (Dustan 1985; Shinn et al. 1989). However, the extent of present, historical, and potential habitat for these two species along the Florida reef tract is not well known.

Recent studies on habitat distributions of both species found *A. cervicornis* distribution to be wider than *A. palmata,* with colonies found on a variety of habitats, including mid-channel and offshore patch reefs, as well as inner reef-tract sites (Miller et al. 2008). Miller et al. (2008) estimated that there may be 13.8 ± 12.0 million *A. cervicornis* colonies and 1.6 ± 1.4 million *A. palmata* colonies throughout the Florida Keys. Unfortunately, a majority of these colonies are undocumented, therefore, the specific habitat type of a majority of the populations can be speculated, but not always verified by observation.

Objectives and Potential Significance

The ESA defines critical habitat as “specific areas within a geographical area occupied by the species at the time of listing, that contain the physical or biological features essential to the species’ conservation, and which may require special management consideration or protection” (1973). The goal of this study is to determine and map the distribution of potential habitat for *A. palmata* and *A. cervicornis* on the Florida reef tract based primarily upon reports of existing colonies and their distributions and abundances. This study will address the reliability and accuracy of both the reported observations and the current benthic habitat maps of the Florida reef tract. The ultimate goal of this study is the creation of probable habitat maps for *A. palmata* and *A. cervicornis* to show areas where these species currently exist, as well as areas that would be suitable for their (re)establishment. These maps may be used to help refine the critical habitat map originally generated by NOAA, at the time of listing of the species.

The results of this research have the potential to be used to define where conservation actions will be most effective. With existing populations mapped, the results will also aid in preventing the destruction of the limited areas in which these species still occur. The resulting dataset on existing populations can also be used by researchers to compare characteristics of locations where these species are still thriving, with the characteristics of areas from which they have disappeared. Such comparisons could, for example, inform choices for likely sites for successful restoration projects. By protecting and restoring populations of these species that provide habitat for many reef fish, the commercial and recreational fishing industries will also potentially be enhanced. Preservation of these species will have benefits for many other organisms that rely on *Acropora* thickets for shelter.

Table 1: Chronological summary of historical observations of *A. palmata* and *A. cervicornis* and perturbation events influencing both species throughout southeast Florida.

Citation	Species		Location	Date	Perturbation Event/Condition
	A. palmata	*A cervicornis*			
(Mayer 1903)	*x*	*x*	Dry Tortugas	1878	Blackwater event
(Agassiz 1882)	*x*		Bird, Bush and Long Keys – Dry Tortugas	1882	
(Wells 1932)	*x*		Bird, Bush and Long Keys	1932	
(Jaap 1979)	*x*		Middle Sambo Reef	Fall 1973	Bleaching
(Dustan and Halas 1987)	*x*	*x*	Carysfort Reef	1974-1982	Slight increase in *A. palmata*, 18% decrease in *A. cervicornis*; Evidence of vessel groundings
(Miller 2003)		*x*	Dry Tortugas	1976-77	Severe cold front
Jaap (unpub.)	*x*	*x*	Elkhorn reef	1977-1981	Stable *A. palmata* populations, demise of *A. cervicornis* due to disease and storms
(Davis 1982)	*x*		Dry Tortugas	1977	Absence of *A. palmata*
(Jaap 1998)		*x*	Dry Tortugas	1979	Hypothermal meterological event (cold-snap)
(Aronson and Precht 2001b)			Florida and Caribbean-wide	1980s	White Band Disease outbreak
(Dustan and Halas 1987)			Lower Keys	June 1980	Bleaching
Jaap et al (unpub.)		*x*	French reef	1981-1986	100% loss of 175 *A. cervicornis* colonies
Jaap (unpub.)	*x*	*x*	Elbow and French reef	1981-1986	Stable *A. palmata*, demise of *A. cervicornis* due to disease and storms
(Jaap 1998; Porter et al. 2001)	*x*	*x*	Key Largo, Carysfort, Grecian Rocks, Key largo Dry Rocks, Elbow, French and Molasses	1981	White disease
(Jaap et al.		*x*	Molasses Reef	1981	

1988)					
(Jaap et al. 1988)	*x*		Key Largo National Marine Sanctuary	Winter 1981-1982	Winter storm fragmented *A. palmata* colonies
(Jaap 1985; Causey et al. 2000)			Lower Keys	Late Summer 1983	Bleaching
(Bohnsack 1984)	*x*	*x*	Looe Key National Marine Sanctuary	1983	Dense thickets – often covering entire reef sections
(Lessios et al. 1983; Lessios et al. 1984; Hallum 1993; Causey et al. 2000)			Caribbean-wide	1983	*Diadema antillarum* mass mortality
(Porter and Meier 1992)	*x*		Looe Key National Marine Sanctuary	1984-1991	44% loss of *palmata*
(Jaap et al. 1988)	*x*		Key Largo National Marine Sanctuary	Fall 1985	Hurricanes Kate and Elena fragmented *A. palmata*
(Jaap et al. 1988)		*x*	Molasses Reef	1986	Loss of *A. cervicornis*
(Causey et al. 2000)			Looe Key National Marine Sanctuary	May-September 1986	Large outbreak of black-band disease
(Causey et al. 2000)			Florida Keys	June 1987	3 weeks of severe coral bleaching
(Causey et al. 2000)			Florida Keys	1989	Slight Bleaching
(Causey et al. 2000)			Florida Keys	July 1990	Massive coral bleaching – near-shore waters for the fist time
(Jaap and Sargent 1994)	*x*		Dry Tortugas	1993	Increase from $200m^2$ in 1977 to $1400m^2$ in 1993
(Miller et al. 2002)			Looe Key National Marine Sanctuary	1994	Major ship grounding
(Hoegh-Guldberg 1999; Causey et al. 2000; Miller et al. 2002)			Worldwide	1997-1998	Widespread bleaching
(Causey et al. 2000; Miller et al.				Summer 1998	Hurricane Georges and tropical storm

2002)					Mitch
(Somerfield et al. 2008)	*x*		Rock Key and Western Sambo	1998-1999	Decline but no disappearance
(Miller et al. 2002)	*x*	*x*	Looe Key national Marine Sanctuary	2000	Occurred in low density solitary colonies – 93% loss of *A. palmata*, 98% loss of *A. cervicornis*
(Thomas et al. 2000)		*x*	Fort Lauderdale	2000	Significant stands
(Hu et al. 2003)			Between Marco island and key west	2002	Black water event
(Vargas-Angel et al. 2003)		*x*	Between port everglades and Hillsboro inlet	July-August 2002	White band disease – no bleaching, predation by H. *carunculata*
(Banks et al. 2008)			Southeast Florida	1987;1992;1999;2004;2005	Hurricanes Floyd, Andrew, Irene, Frances, Katrina and Wilma
(Miller et al. 2007)	*x*		Carysfort reef, Elbow reef, Horseshoe reef, French reef, Molasses reef, Sand Island, Sombrero Key and Looe Key	2007	Extensive thickets
(Miller et al. 2007)	*x*	*x*	Carysfort reef	2007	Lobster trap entanglements

METHODS

Field area

The Florida reef tract extends from Martin County to the Dry Tortugas and hosts a fringing reef that contains a combination of patch, linear and aggregate reefs. The reef tract occurs near the latitudinal limits of subtropical waters and, thus, experiences an abundance of natural stressors. Conditions along the reef tract include variable temperatures reaching extreme highs and lows, which are not generally favorable for reef development. Nevertheless, corals continue to occur in this region (Kruczynski and McManus 2002).

For this project, the reef tract has been subdivided into three regions, southeast Florida, Florida Keys and the Dry Tortugas (Figure 1). Previous studies defined the terminus of the Florida Keys reef tract at Fowey Rocks (Vaughan 1914; Jaap et al. 1984; Shinn et al. 1989), as such the boundary between the Florida Keys region and the southeast Florida region was set off Biscayne Bay near Fowey Rocks. My study uses the term “southeast Florida” (SE Florida) to represent the continental shelf portion of Florida extending from Martin County to Biscayne Bay, where the southeast Florida reef tract begins (Banks et al. 2007). The region of the Florida reef tract extending from Fowey Rocks to the Marquesas Keys will be referred to as “the Keys” and the region encompassed by the Dry Tortugas National Park and surrounding areas will be referred to as the “Dry Tortugas” (Figure 3).

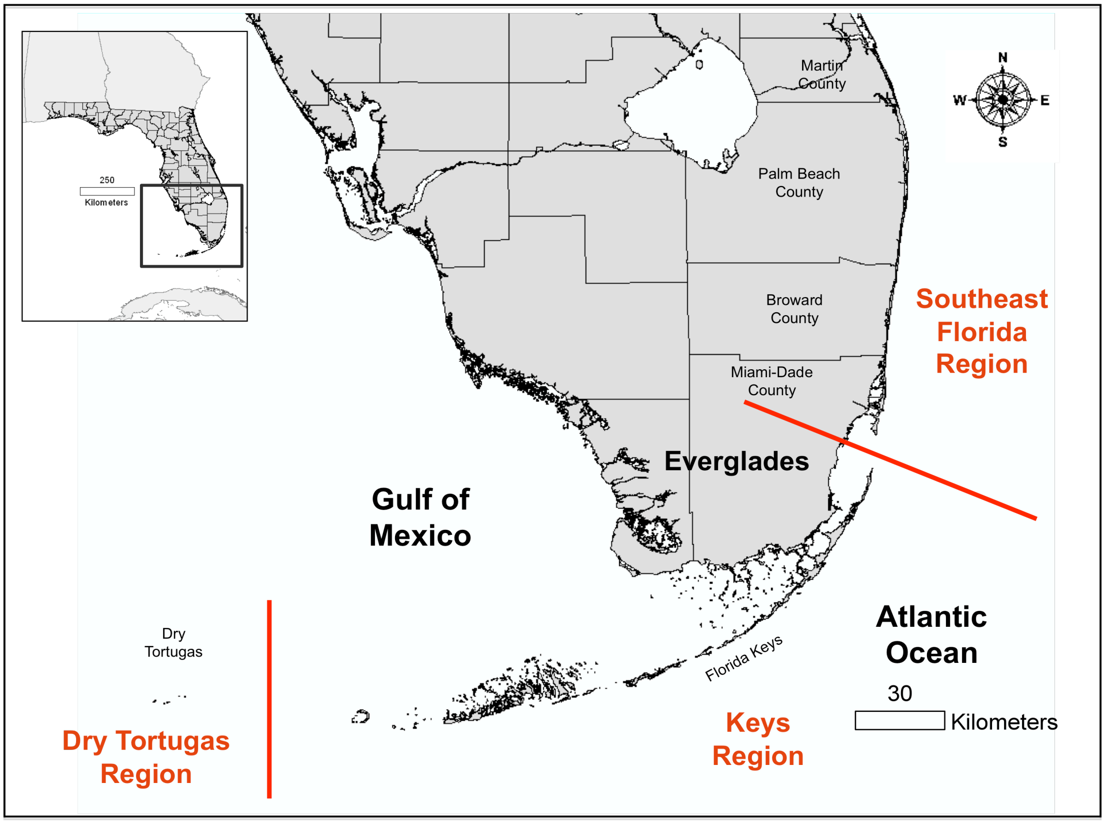


Figure 3: Map of sub-regions of the Florida reef tract used for this study

Data

The Florida Fish and Wildlife Research Institute (FWRI) has been provided with *Acropora* spp. location data along the Florida reef tract, from Martin County to the Dry Tortugas. The observations have been reported from a wide range of groups, agencies and institutions, including CREMP, University of Miami, National Coral Reef Institute (NCRI), and The Nature Conservancy (TNC), as well as by independent divers. Observations were reported from surveys between 1996 and 2009.

The data sets were provided in various formats and thus required organization to a unified form. Latitudes and longitudes were transformed into decimal degree (DD) from degree-minute-second (DMS) or Universal Transverse

Mercator (UTM) formats. All information regarding abundance was removed and replaced with either presence or absence of each species. Presence is defined as an area that was surveyed and the species was present on the given date. Absence is defined as an area that was surveyed and the species was not present on the given date. At a minimum, all location data points included latitude, longitude, date of sighting, and species (*A. palmata, A. cervicornis, A. prolifera,* or absence*)*. Some data sets provided information such as depth, condition of the colony and notes; these data were retained in the final compiled database.

These data were then converted to GIS shapefiles and used to populate an *in situ* observation map of reported *Acropora* spp. presence using ESRI's ArcGIS software. The database was then split into four categories: *A. palmata* presence, *A. cervicornis* presence, dual species presence, and absence. All data were then quality checked. Any points occurring outside of logical regions were removed from the database. For example, a few points were reported to occur in the mid-Atlantic. If there was no way to correct an obviously erroneous report, it was removed.

Benthic Habitat Maps

Several groups throughout South Florida including FWRI, National Oceanic and Atmospheric Administration (NOAA), Dade County, and Nova Southeastern University/NCRI, have previously mapped the benthic habitat of a majority of the Florida reef tract. The mapping techniques for each region varied slightly, but were similar enough to be used together to identify benthic habitat throughout the reef tract.

Information on benthic habitat maps used for this study is provided in Table 2. The southeast Florida region maps were produced using a combination of Laser Airborne Depth Sounder (LADS) bathymetry, acoustic ground discrimination, aerial photography, and high-resolution bathymetry methods to distinguish between ‘coral reef’, ‘colonized hardbottom’, ‘bare substrate’, and ‘other’ habitats (Figures 4,5,6). The mapping done in the south Florida region was done by visual interpretation of aerial photography (Figure 7).

Table 2: Details on the multiple benthic habitat maps used for this study

Sub-region	Location	Year	Year of Source Imagery	Agency	Minimum Mapping Unit	Area covered
Southeast Florida	Palm Beach County	2002	2003-2004	FWRI and Nova Southeastern University	1 acre	254 km^2
	Broward County	2004	2003-2004	FWRI and Nova Southeastern University	1 acre	110 km^2
	Miami Dade County	2009	2003-2004	Nova Southeastern University	1 acre	240 km^2
Florida Keys	Florida Keys	1998	1991-1992	FWRI and NOAA	1 acre	5,094 km^2
	Biscayne Bay	1995	1991-1992	FWRI and Dade County	1 acre	
Dry Tortugas	Dry Tortugas	1998	1991-1992	FWRI and NOAA	1 acre	508 km^2

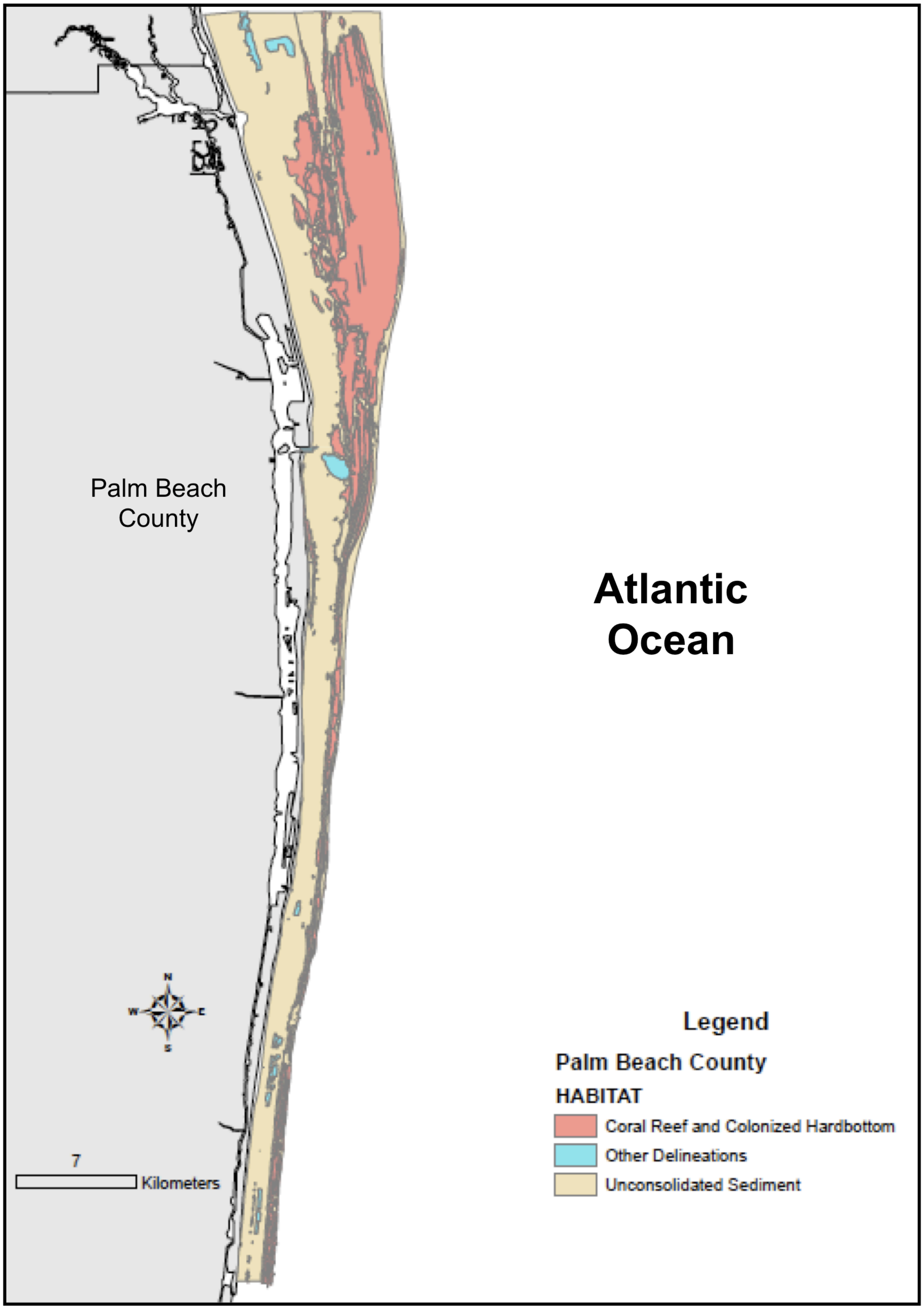


Figure 4: Map of benthic habitat off Palm Beach County used for this study (Florida Fish and Wildlife Research Institute and Nova Southeastern University 2002).

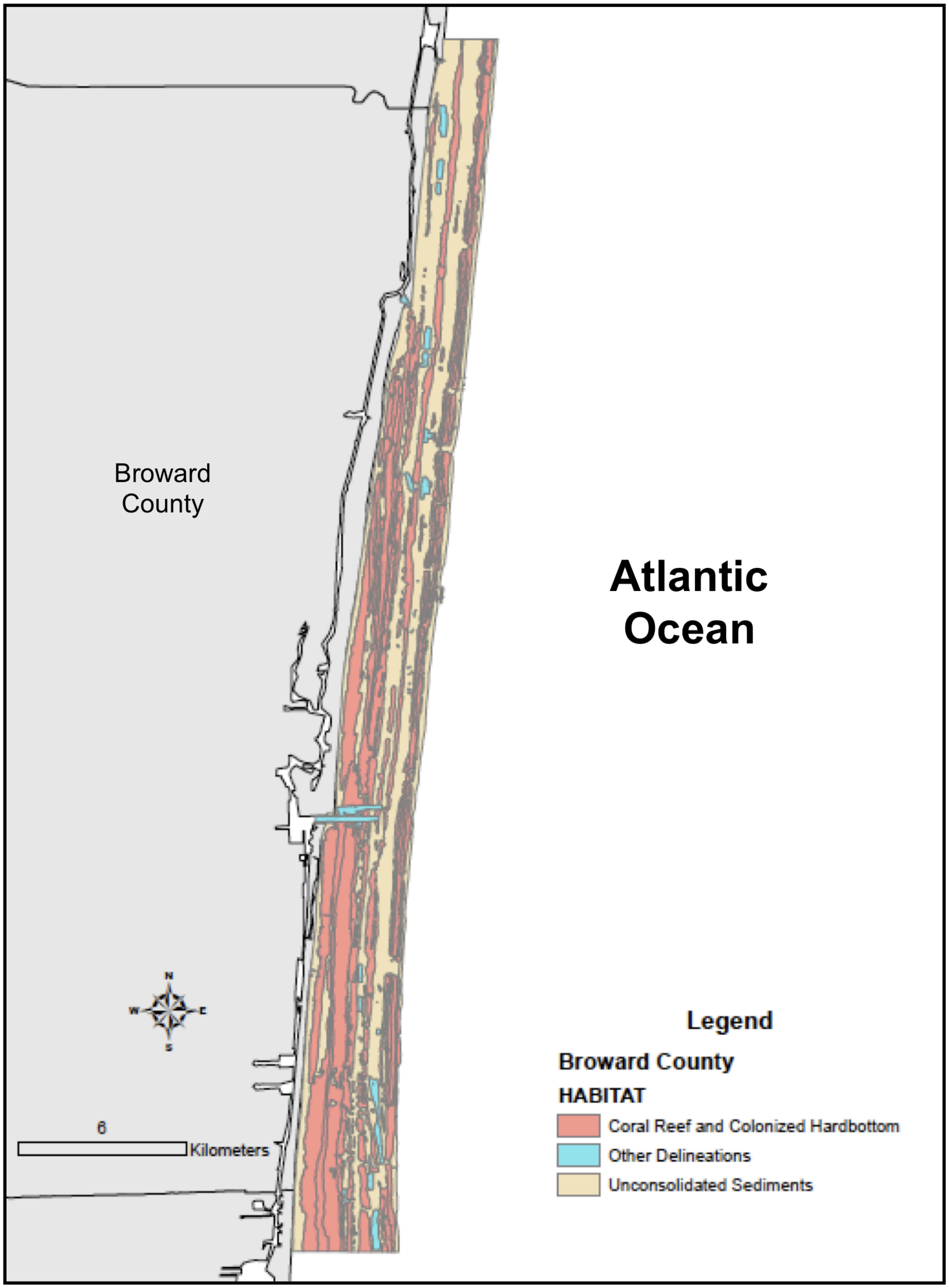


Figure 5: Map of benthic habitat off Broward County used for this study (Florida Fish and Wildlife Research Institute and Nova Southeastern University 2004).

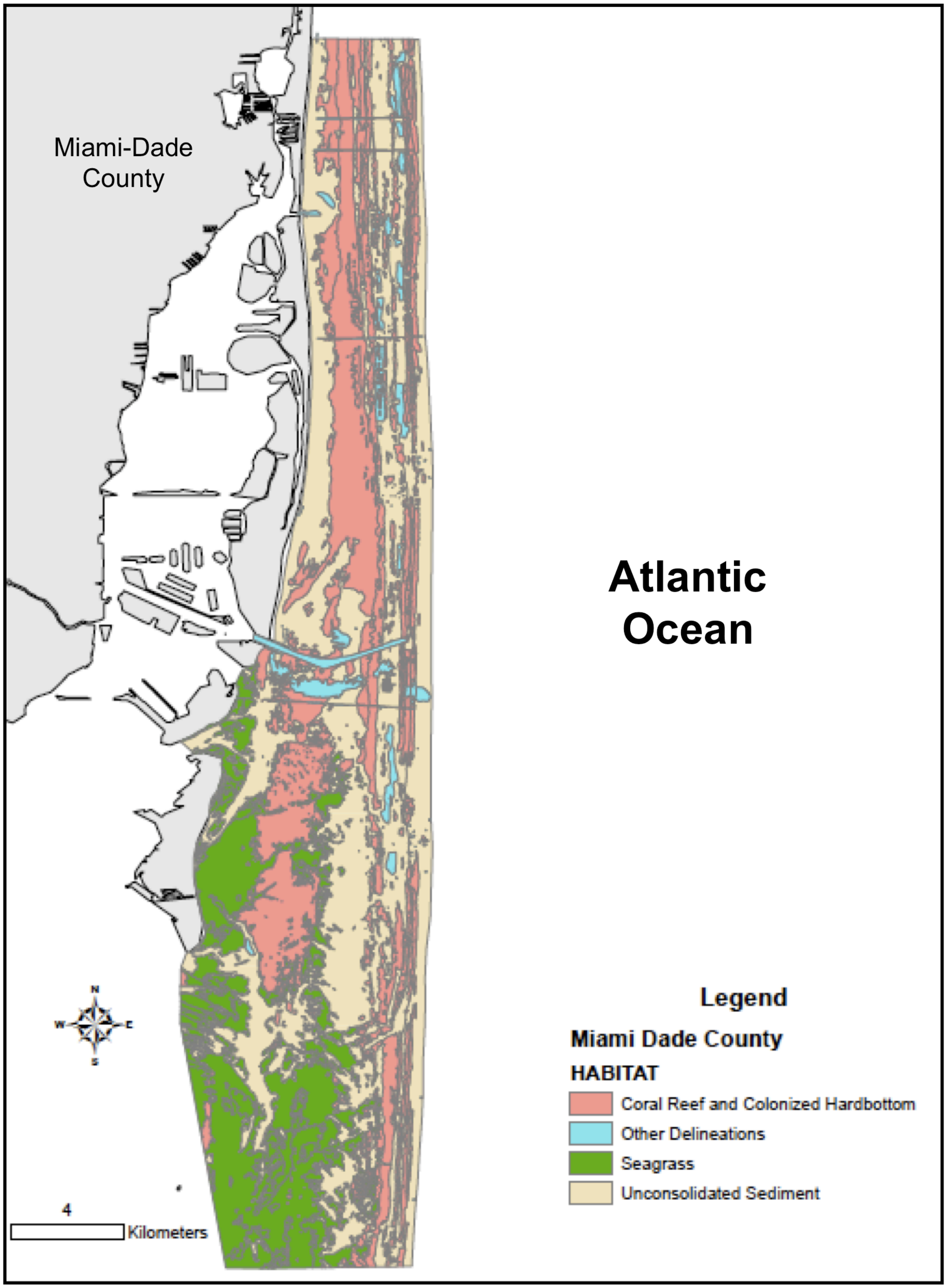


Figure 6: Map of benthic habitat off Miami-Dade County used for this study (Walker 2009).

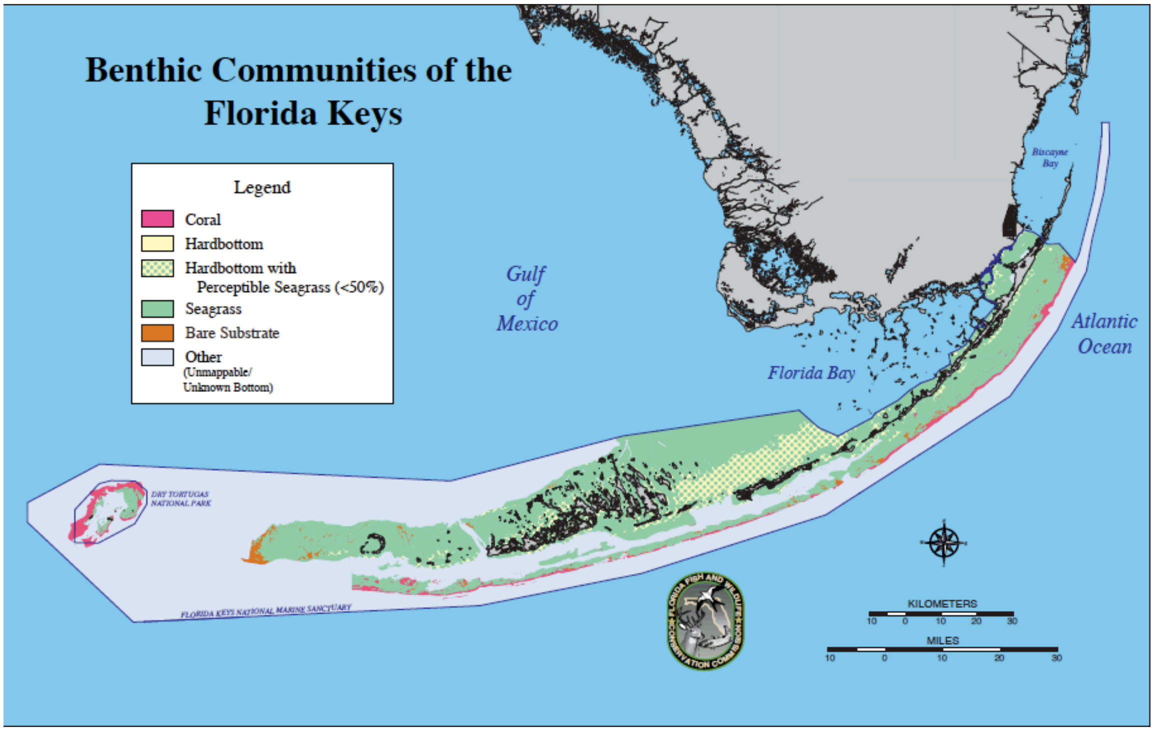


Figure 7: Overview of Florida Keys Benthic Habitat map as produced by FWRI in 1998 (Florida Fish and Wildlife Conservation Commission-Fish and Wildlife Reseach Institute et al. 1998).

New Dry Tortugas Habitat Map

In 2008 FWRI contracted Avineon, Inc, to create a new benthic habitat map for Dry Tortugas National Park. The new map was interpreted from IKONOS satellite imagery using a minimum mapping unit of 1,011.7 m^2 (Figure 8). For my study, the term “old Dry Tortugas habitat map” will be used to refer to the benthic habitat map created in 1995 and the term “new Dry Tortugas habitat map” will refer to the benthic habitat map created in 2008. The same method used for the other habitat maps was used to determine *Acropora* spp. habitat. Buffers were also created and examined as with the other regional habitat maps. The results from the new Dry Tortugas habitat map were tested using the K-S test for goodness of fit to determine if distributions based on the new habitat map differed significantly from the overall cumulative percentage distribution. A third

K-S test for goodness of fit was used to determine if cumulative percentages in each buffer distance of the new Dry Tortugas habitat map differed significantly from the cumulative percentage distribution based on the old Dry Tortugas habitat map.

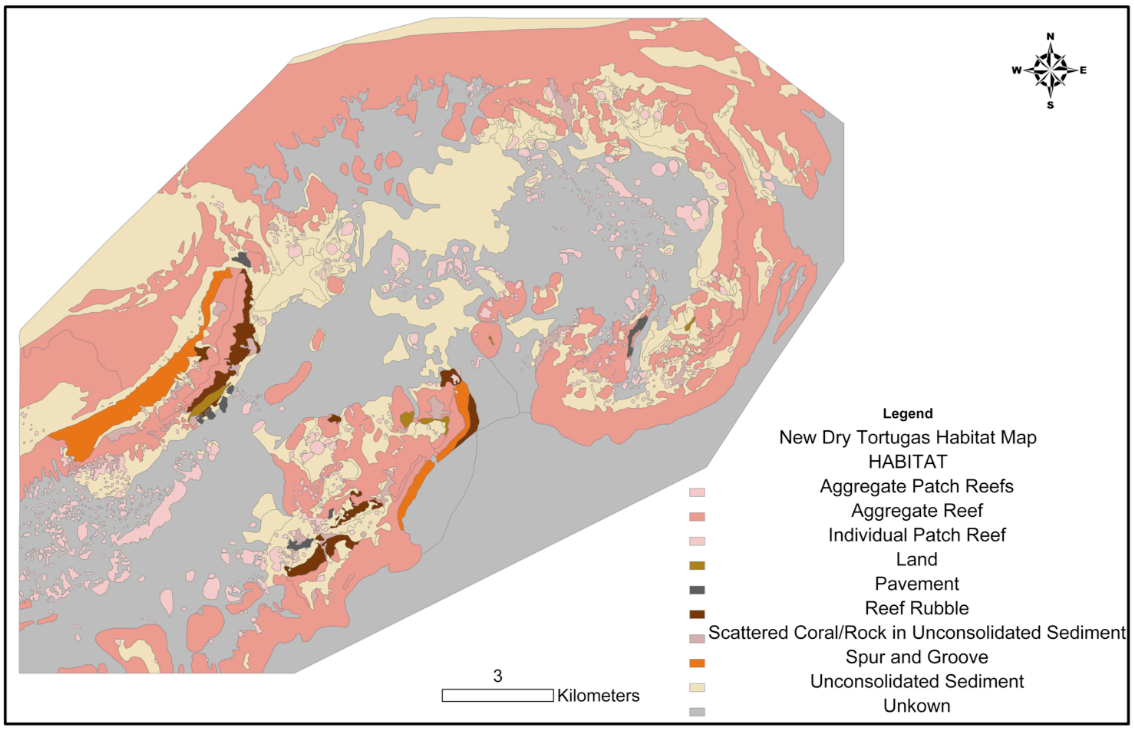


Figure 8: Overview of new Dry Tortugas benthic habitat map as produced by FWRI in 2008.

Determination of Acropora Habitat

Using ESRI's ArcGIS software, the *in situ Acropora* spp. observation location database was overlaid on the benthic habitat maps. Observations located completely within mapped coral reef or hardbottom were identified. The various classifications of coral reef and hardbottom used from the maps are shown in Table 3. The points located outside of reef or hardbottom were extracted and further examined. For each point not on coral reef or hardbottom, the type of substrate was determined as 'seagrass', 'bare substrate', ‘unmappable/uninterpretable’, or ‘unmapped’. Distance to the nearest coral reef or hardbottom polygon was also calculated for each observation.

Table 3: Coral reef and hardbottom classifications used from the benthic habitat maps in this study

Classification	Maps					
	Palm Beach	Broward	Miami Dade	Biscayne	Florida Keys	Dry Tortugas
Aggregated Patch Reef	x	x				
Colonized Pavement	x	x	x			
Hardbottom					x	
Hardbottom with perceptible seagrass				x	x	x
Linear Reef	x	x	x			
Patch Reef	x	x	x	x	x	x
Platform Margin Reef				x	x	x
Ridge	x	x	x			
Scattered Coral/Rock in Sand		x	x			
Spur and Groove	x	x	x			

Buffer Generation

Buffers were created around mapped coral reef and hardbottom at various distances ranging between 1 and 400 m and the number of points included within each buffer distance was determined. Buffers were created at 1 m increments, until exactly 95% and 99% of all points were included.

Observations were then separated into the three regions: Keys, Dry Tortugas, and Southeast Florida. The percentage of points within each buffer size was identified to determine the cumulative distribution of the three regions. A Kolmogorov-Smirnov (K-S) test for goodness of fit (Sokal and Rohlf 1981) was performed to determine if any of the three regions differed significantly from the overall cumulative percentage distribution ($\propto = 0.05$). The K-S test was performed for both species combined, *A. palmata* only, and *A. cervicornis* only.

Bathymetry

FWRI, in conjunction with GEONEX, digitized nearshore bathymetry for coastal Florida from NOAA nautical charts in 1992. A bathymetry shapefile using line and depth regimes depicted as polygons was used to determine depth for each point. The bathymetry was grouped in seven different ranges: 0 – 3 ft, 3 – 6 ft, 6 – 12 ft, 12 – 18 ft, 18 – 30 ft, 30 – 60 ft, and 60 – 100 ft (English units were used to be consistent with existing bathymetric maps). The *Acropora* spp. observations were overlaid on the bathymetry map to determine the depth range of each observation.

Probable Habitat Generation

Based on the frequencies in the various buffer sizes and the result of the K-S tests, probable habitat was created by merging the coral reef and hardbottom buffered zones from each of the three regions. This probable habitat depicts areas where *Acropora* spp. should be located, based on habitats of previously observed colonies. The database on *Acropora* spp. locations is designed to be regularly updated. The resulting probable habitat map from this study will also be updatable, thereby allowing continuing development of a database to enhance management decisions to protect these threatened species.

RESULTS

A total of 7,849 observations of *Acropora* spp. presence in Florida were reported to the database. The majority of the observations were reported for *Acropora palmata* presence, with 5,050 observations, compared to 2,799 observations for *A. cervicornis* presence (Table 4). Most were from the Florida Keys, with a total of 7,329 presence observations. Only 90 observations were reported from the Dry Tortugas. A majority of *A. palmata* observations also were from the Keys region, with few observations reported in the Dry Tortugas and southeast Florida, 5 and 11, respectively. A total of 1,863 absence points were submitted to the database. While locations of surveys that did not detect *Acropora* spp. are important, they were not addressed in this study. All further results pertain to locations where surveys detected one or both species of *Acropora*.

Table 4: Number of observations reported to the database in each of the three regions of the Florida reef tract

Observation	Keys	Dry Tortugas	Southeast Florida	All Florida
Acropora palmata presence	5,034	5	11	5,050
A. cervicornis presence	2,295	85	419	2,799
Total Presence	**7,329**	**90**	**430**	**7,849**
Absence	1,652	129	82	1,863
Total Observations	**8,981**	**219**	**512**	**9,712**

Of the 7,849 records only 19 (0.24%) were clearly erroneous. Nine observations were removed from the Keys data set, two from the Dry Tortugas, and eight from southeast Florida, based on unreasonable locations in relation to bathymetry and the Florida coastline (Table 5). Eight reported observations of *A. cervicornis* off Southeast Florida were removed as the locations corresponded to depths greater than 300 ft (91 m). Two removed observations of *A. palmata* in the Keys were located on land, as were several of the *A. cervicornis* removed observations. One observation of *A. cervicornis* in the Keys was located approximately 2,000 m southeast of Looe Key National Marine Sanctuary at a depth of approximately 160 ft (49 m). The notes for this particular observation stated that it was at a patch west of Looe Key. Therefore, it was assumed that there was an error in the latitude and longitude. These types of errors appeared to occur in several of the other removed observations.

Table 5: Number of observations of *Acropora* spp. by region of the Florida reef tract after erroneous points were removed from the database

Observation	Keys	Dry Tortugas	Southeast Florida	All Florida
Acropora palmata presence	5,032	5	11	5,048
A. cervicornis presence	2,288	83	411	2,782
Total Presence	**7,320**	**88**	**422**	**7,830**

Habitats of Acropora spp. Observations

A total of 7,292 observations coincided with previously mapped reef or hardbottom, encompassing 93% of all observations (Table 6). Most of the observations in southeast Florida were located on mapped reef or hardbottom (97%). All *A. palmata* observations from both the Dry Tortugas and southeast

Florida, coincided with mapped reef or hardbottom, as were 99% of the *A. palmata* observations in the Keys region. On the other hand, 83% of the *A. cervicornis* observations coincided with mapped reef or hardbottom. So an important question that can be addressed using this data set is: “Do the data points that do not fall on mapped reef or hardbottom represent mapping errors, the potential for *A. cervicornis* to occupy habitats other than reef or hardbottom, or do some other issues play a role?”

Table 6: Observations corresponding to mapped coral reef or hardbottom across the various regions of the Florida reef tract

	Keys		**Dry Tortugas**		**Southeast Florida**		**All Florida**	
	n	%	n	%	n	%	n	%
A. palmata	4,797	99	5	100	11	100	4,995	99
A. cervicornis	1,844	81	55	73	398	97	2,297	83
Total	6,823	93	60	75	409	97	7,292	93

All *A. palmata* observations in southeast Florida were located on mapped coral reef or hardbottom. Of the 13 *A. cervicornis* observations that were located outside of mapped reef or hardbottom in southeast Florida, 9 (69%) were located on ‘sand’, followed by 3 (23%) in ‘unmapped’ regions, and 1 (8%) on ‘artificial’ habitat (Figure 9). The unmapped regions where observations of *A. cervicornis* occurred extended further offshore than the mapped habitat.

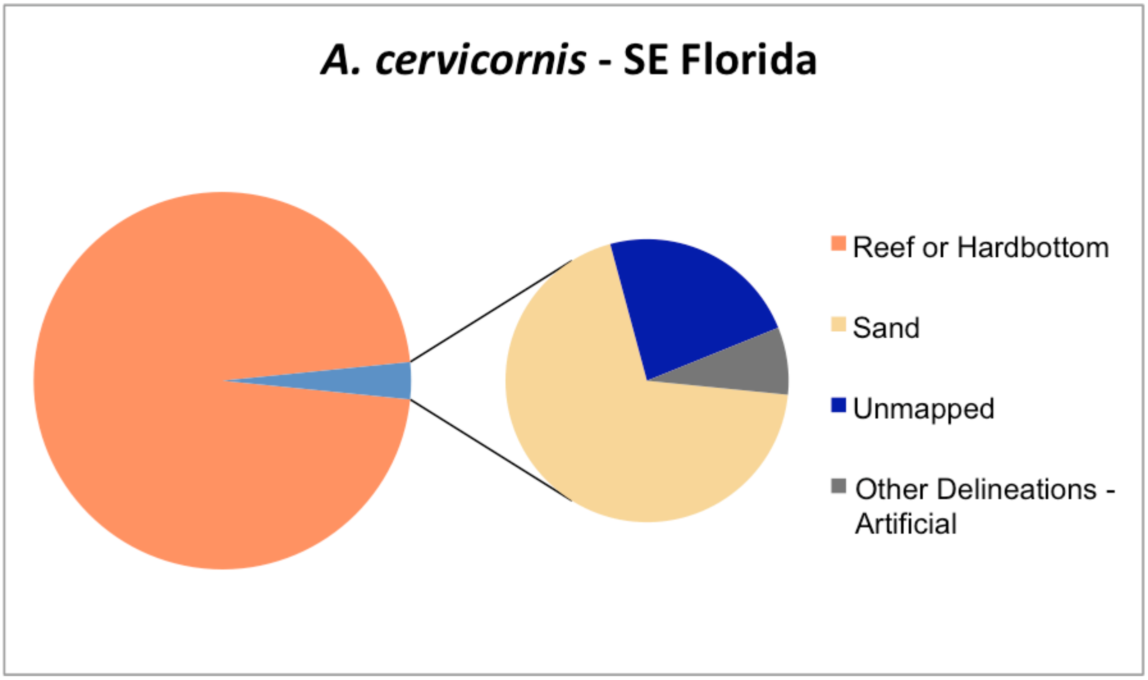
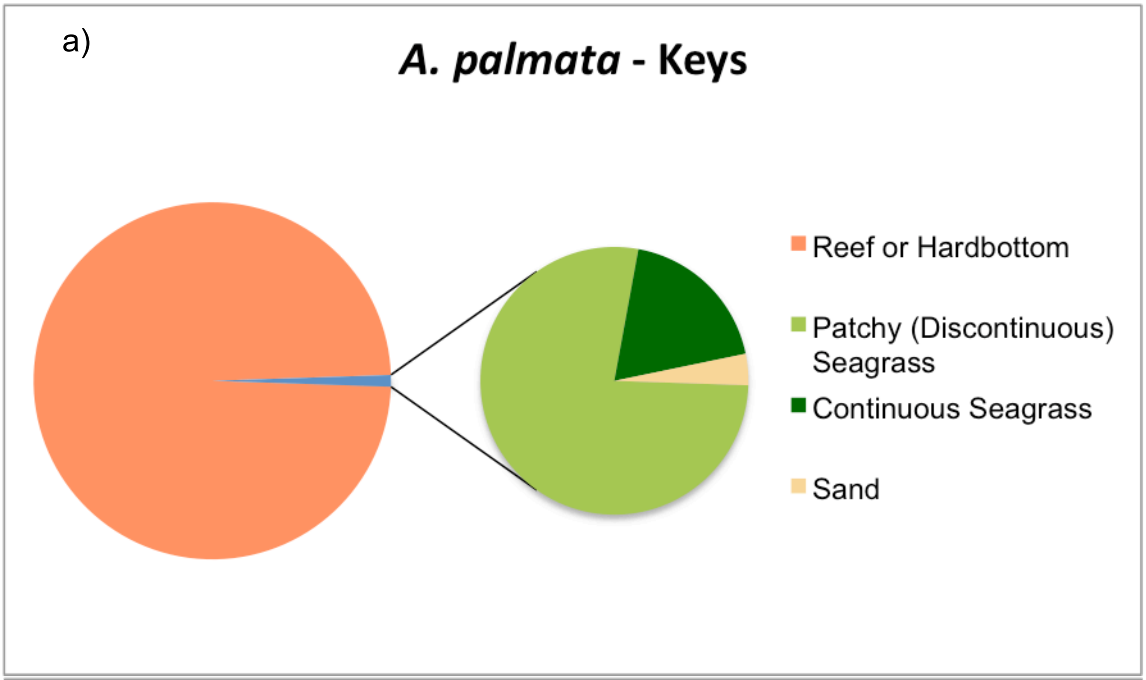


Figure 9: Associated substrate of locations of *A. cervicornis* presence not coinciding with mapped coral reef or hardbottom for southeast Florida. 'Sand' - 69%; 'unmapped' - 23%; 'other delineations – artificial' - 8%

Both *A. palmata* and *A. cervicornis* were found outside mapped reef or hardbottom in the Keys region (Table 4, Figure 10). The 53 *A. palmata* observations corresponded with mapped 'seagrass' (96%), primarily 'patchy seagrass' (41 observations = 77%), but also, 'continuous seagrass' (10 observations = 19%), as well as 'sand' (2 observations = 4%). Similarly, the 444 *A. cervicornis* observations included 'seagrass' (403 observations = 91%) and 'sand' (4 observation = 1%), but also areas that were 'unmapped' (15 observations = 3%) or 'unmappable' (22 observations = 5%; Figure 9). Data from the Keys drives the pattern for the full reef tract, because most of the observations came from this region.

As in southeast Florida, all observations of *A. palmata* in the Dry Tortugas were located on mapped reef or hardbottom. Interestingly, of the 28 observations of *A. cervicornis* that were located outside of mapped reef or hardbottom, a majority were located in ‘unmappable’ or ‘unmapped’ areas (27 observations = 96%), with only one observation (4%) on ‘continuous seagrass’ (Figure 11). This observation may be attributed to the greater abundance of unmappable regions located in the Dry Tortugas, as much of the lagoon area was considered to be unmappable.

Because the Keys region dominated the data set, the percentages across the entire reef tract are driven largely by those data. This is completely the case for *A. palmata,* which was only found outside previously mapped reef or hardbottom in the Keys region. Of the 1,672 observations recorded for *A. cervicornis,* 84% coincided with mapped reef or hardbottom (Figure 12). The next most common habitats were ‘continuous seagrass’ at 10% of observations and ‘patchy seagrass’ at 2%. ‘Sand’, ‘artificial’, ‘unmapped’, and areas that were not identifiable during the mapping process (‘unmappable/uninterpretable’) account for the locations of the remaining 4% of the *A. cervicornis* observations (Figure 11).



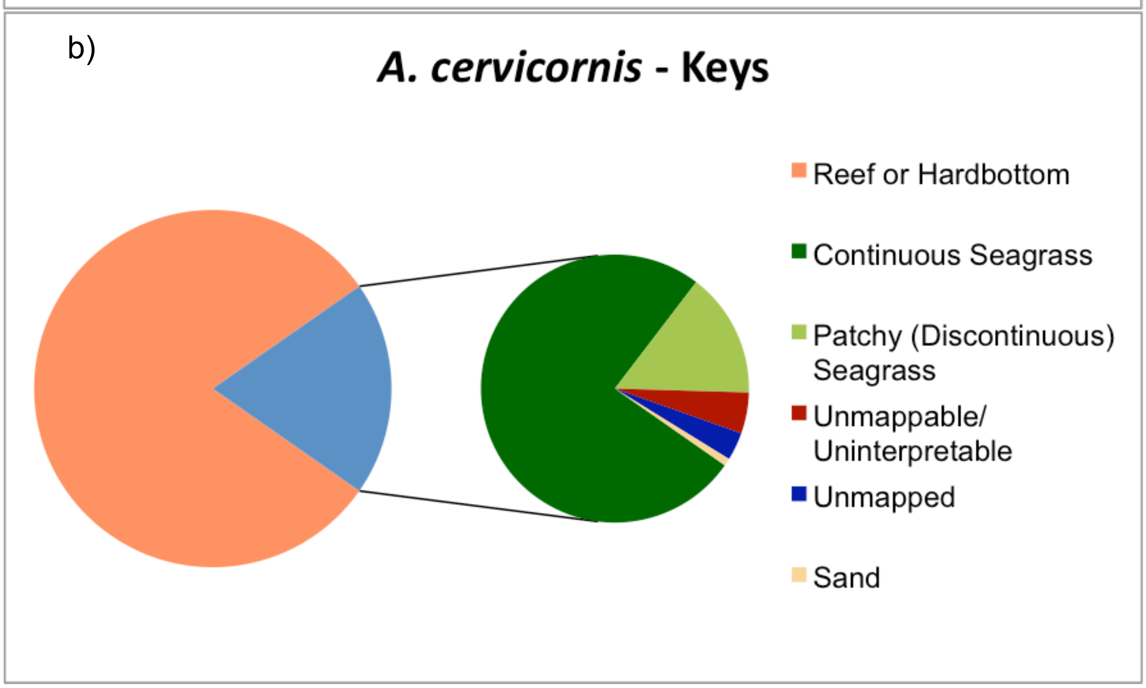


Figure 10: Associated substrate of locations of *Acropora* spp. presence not coinciding with mapped coral reef or hardbottom for the region of the Florida Keys. a) n = 53;'patchy (discontinuous) seagrass' - 77%; 'continuous seagrass' - 19%; 'sand' - 4%; b) n = 444; 'continuous seagrass' – 76%; 'patchy (discontinuous) seagrass' – 15%; 'unmappable/uninterpretable' – 5%; 'unmapped' – 3%; 'sand' – 1%

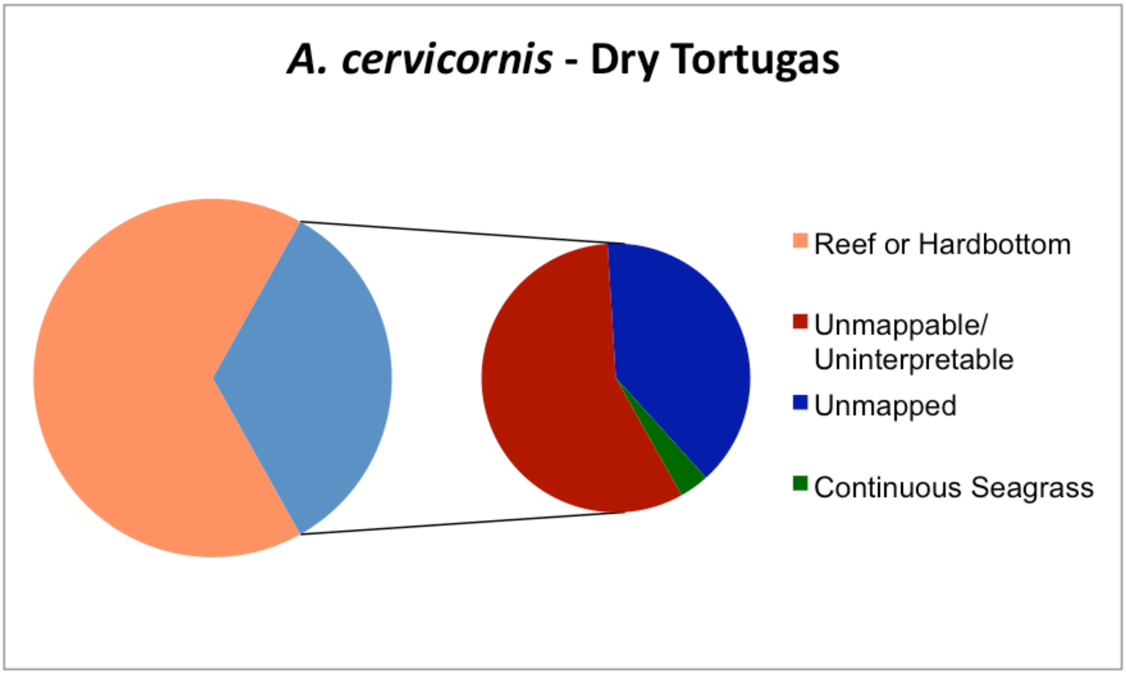


Figure 11: Associated substrate of 28 locations of *A. cervicornis* presence not coinciding with mapped reef or hardbottom for the Dry Tortugas. 'Unmappable/uninterpretable' - 57%; 'unmapped' - 39%; 'continuous seagrass' - 4%

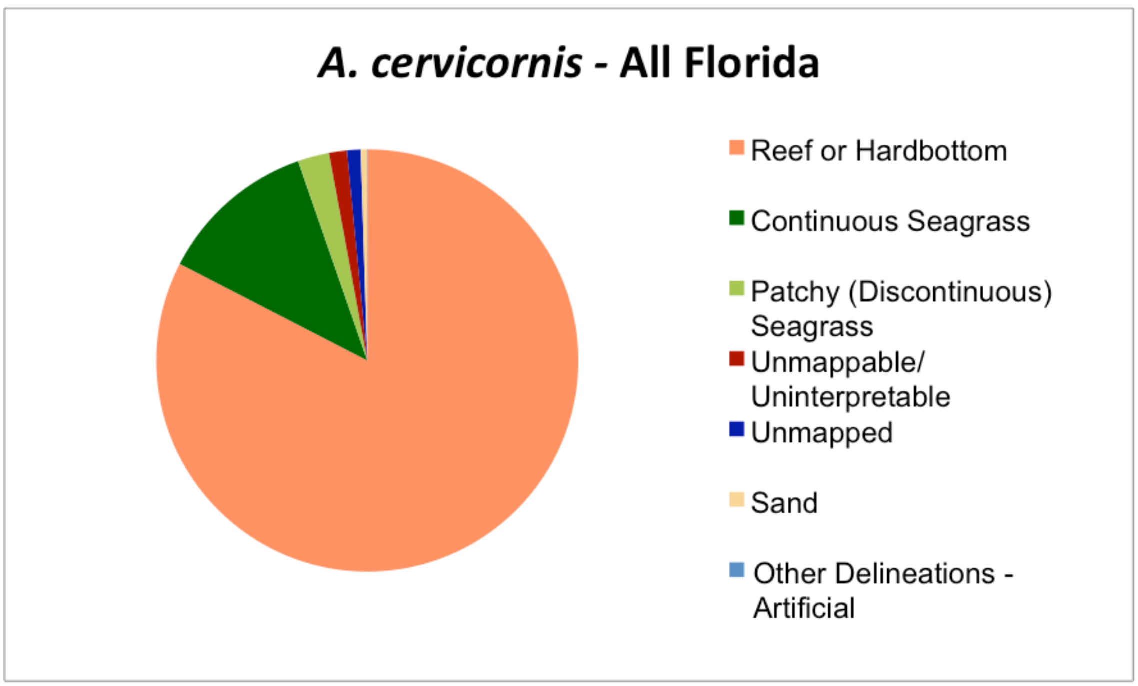


Figure 12: Associated substrate of locations of *Acropora cervicornis* presence along the entire reef tract. Reef or hardbottom – 83%; 'continuous seagrass' - 12%; 'patchy (discontinuous) seagrass' – 2%; 'unmappable/uninterpretable' – 1.4%; 'unmapped' – 1%; 'sand' – 0.5%; 'other delineations – artificial' – 0.04%

Proximity to mapped coral reef or hardbottom

For points that did not correspond to reef or hardbottom, distances to nearest reef or hardbottom were calculated for each point. Most points occurred within 100 m of previously mapped reef for both species (Figure 13), with a median distance for *A. cervicornis* of 24 m and for *A. palmata* of 12 m (Table 7). Most *A. cervicornis* observations were located within 120 m of mapped reef or hardbottom (93%). However, eleven observations occurred more than 1000 m away, with eight of those being approximately 7,500 m away. Those eight observations were from a single CREMP survey site located in the Dry Tortugas, which was outside of the extent of the Dry Tortugas mapped habitat. Most *A. palmata* observations were located within 30 m of the mapped coral reef habitat (91%), with all but one located within 100 m.

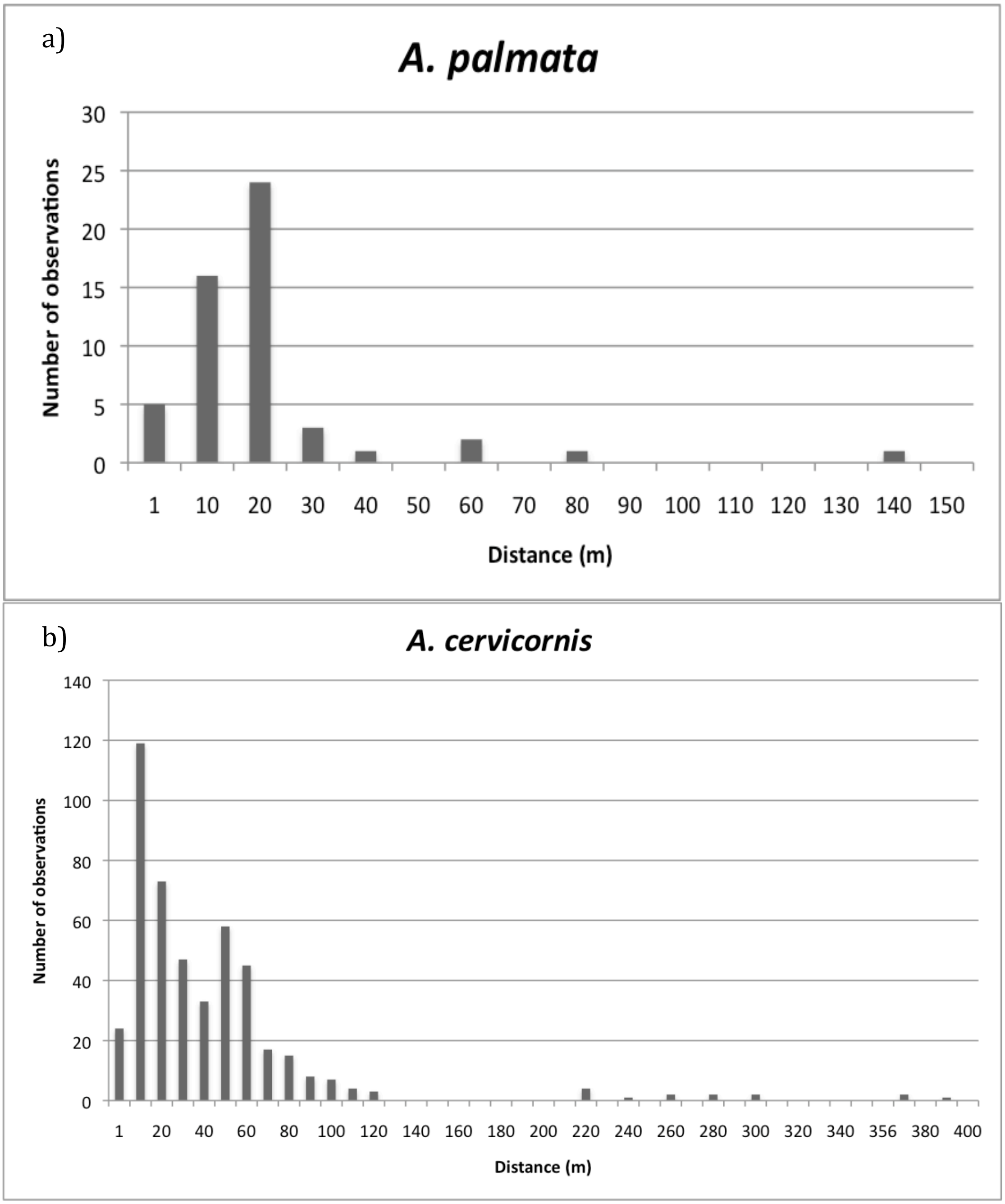


Figure 13: Distances to nearest reef or hardbottom for all reported sightings outside mapped reef or hardbottom in all three regions combined.

Table 7: Statistics of distances of observations to nearest coral reef or hardbottom by species

	A. palmata	*A. cervicornis*
Maximum	135 m	7511 m
Minimum	0.20 m	0.1 m
Median	12 m	24 m
Number	53	485

Buffer Generation

Buffers were generated at distances ranging from 1 m to 400 m. When calculating the percentages of *A. cervicornis* located in the various buffer distances in the Dry Tortugas, the eight points located approximately 7,600 m away were excluded due to their extreme distance from any mapped region. These eight points are likely located on actual reef or hardbottom that simply has not been mapped yet, given that they come from CREMP surveys.

Buffers were generated at 1 m increments at various distances in order to identify the buffer size where exactly 95% and 99% of points were included for each species by region. Table 8 summarizes the distances where these percentages are reached. Figure 14 compares the percentage of points included within each buffer distance by region. For both species combined, observations across the entire reef tract follow the same general trend as observations in the Keys, with slight deviations around 1 m, 55 m and 100 m. Percentages of observations in the Dry Tortugas begin at 75%, but then increase to > 95% by 10 m. Of the observations from southeast Florida, 97% are within the mapped reef and hardbottom and 99% are within 25 m. All (100%) of the *A. palmata* observations in southeast Florida and the Dry Tortugas were included in the mapped reef and hardbottom. Observations of *A. palmata* in the Keys follow the same trend as observations throughout the entire reef tract. Observations of *A. cervicornis* appear to follow similar trends as the combined species observations with high percentages in southeast Florida and lower initial percentages in the Dry Tortugas with a spike at 10 m. Observations of *A. cervicornis* in the Keys have slightly lower percentages than observations throughout the entire reef tract combined but follow the pattern closely at larger buffer distances, since those points are driving the overall trend.

Table 8: Distances where exactly 95% and 99% of points are included in the buffer

	Keys		**Dry Tortugas**		**Southeast Florida**		**All Florida**	
	95%	99%	95%	99%	95%	99%	95%	99%
A. palmata	0m	0m	0m	0m	0m	0m	0m	0m
A. cervicornis	54m	90m	9m	26m	0m	20m	48m	106m
Both species	4m	54m	9m	26m	0m	20m	5m	56m

Results of the K-S test (Table 9) suggest that the distribution of *A. cervicornis* in southeast Florida are significantly more likely to coincide with mapped reef or hardbottom than throughout the entire reef tract. However, the distribution of observations of both species combined in southeast Florida is not significantly different than the distribution across the entire reef tract. Distributions of *A. cervicornis* observations in the Keys and the Dry Tortugas are not significantly different than the entire reef tract, but the distribution of both species combined in the Dry Tortugas is significantly different than the entire reef tract. No distribution of *A. palmata* in any region is significantly different from distributions of the entire reef tract.

Table 9: Results of K-S goodness of fit test - comparing distributions in each region to distributions of the full reef tract. ** designates significance

	A. cervicornis		*A. palmata*		Both Species	
Region	n	$D_{max}/D_{0.05}$	n	$D_{max}/D_{0.05}$	n	$D_{max}/D_{0.05}$
Keys	2,288	1.97/2.84	5,032	0.003/1.91	7,320	0.17/1.59
Dry Tortugas	75	10.77/15.68	5	1.05/60.73	80	18.13**/15.18
SE Florida	411	14.27**/6.70	11	1.05/40.95	422	3.79/6.61

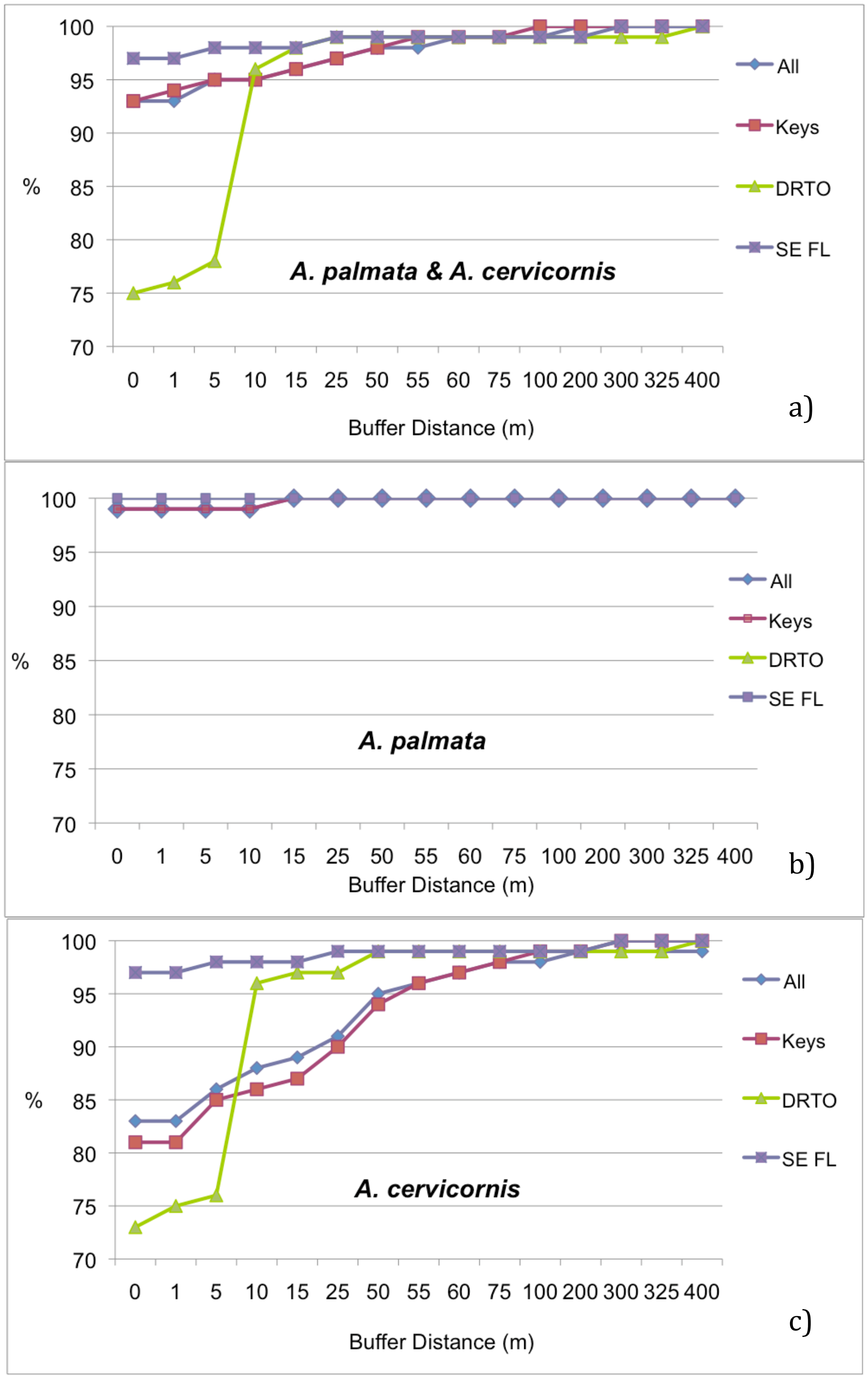


Figure 14: Percentages of points included for various buffer distances by region: a) percentages of both species combined b) percentages of *A. palmata* c) percentages of *A. cervicornis.*

Old vs. New Dry Tortugas Habitat Map

Different results were found when using the more recent benthic habitat map of the Dry Tortugas to determine observations of *A. cervicornis* located on coral reef or hardbottom (Table 10). All five *A. palmata* observations occurred on mapped reef or hardbottom in both cases. When using the older benthic habitat map generated in 1998, only 55 of 75 (73%) *A. cervicornis* points were found coincident with reef or hardbottom. However, when using the more recent and more detailed benthic habitat map of the Dry Tortugas, 72 of the 75 (96%) points were found to be located directly on reef or hardbottom. Figure 15 shows the percentages of points included with each buffer distance of the old and new maps. An interesting note is that by 400 m, the old map includes 100% of points whereas at a buffer distance of 400 m, the new map includes only 97% of points. This is because the newer map does not extend as far northeast and south as the older map, where two observations are located.

Table 10: Points located on mapped reef or hardbottom comparing the old Dry Tortugas map to the new Dry Tortugas map

	1995 DRTO		2008 DRTO	
	n	%	n	%
A. palmata	5	100	5	100
A. cervicornis	55	73	72	96
Total	**60**	**75**	**77**	**96**

Results of the K-S test (Table 11) suggest that the distribution of *A. cervicornis* based on the new Dry Tortugas habitat map are not significantly more likely to coincide with mapped reef or hardbottom than throughout the entire reef tract. However, results of a K-S test comparing distributions of *A. cervicornis* based on the old habitat map to distributions of *A. cervicornis* based on the new habitat map suggests that observations of *A. cervicornis* are significantly more likely to coincide with mapped reef or hardbottom based on the new habitat map than based on the old habitat map.

Table 11: Results of KS test comparing distributions based on the new Dry Tortugas habitat map to all Florida as well as the new Dry Tortugas habitat map to the old Dry Tortugas habitat map

	A. cervicornis	
	n	$D_{max}/D_{0.05}$
2008 DRTO to All Florida	75	13.43/15.68
1995 DRTO to 2008 DRTO	75	22.67*/15.68

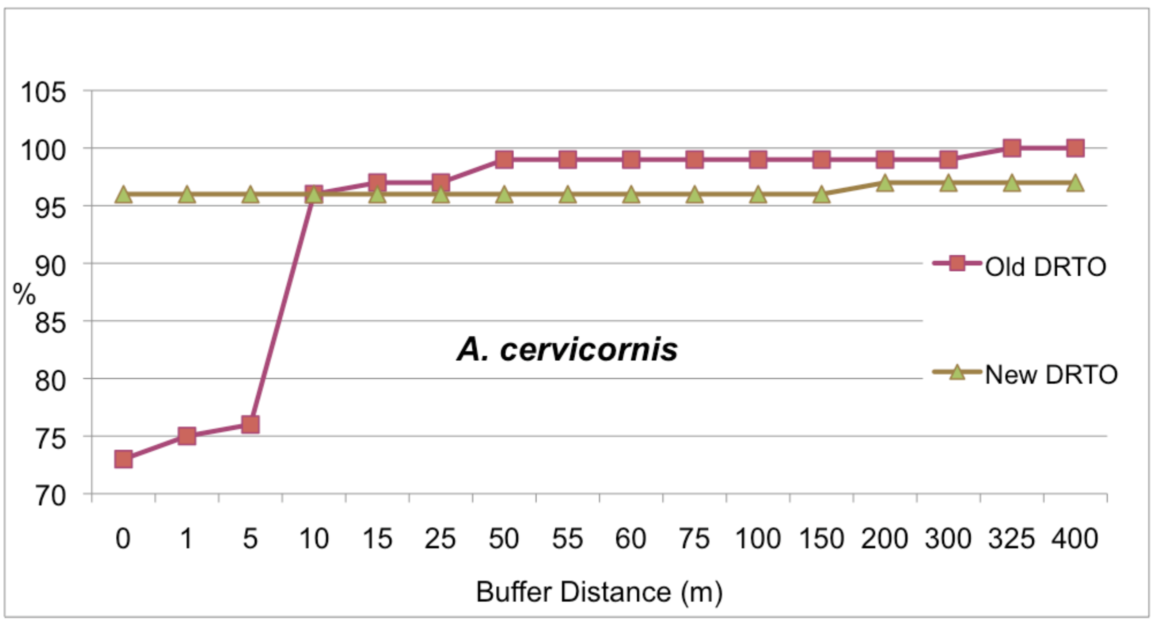


Figure 15: Percentages of *A. cervicornis* observations included with various buffer distances; old Dry Tortugas Habitat map vs. new Dry Tortugas habitat map.

Bathymetry

After editing the data set for reports that were clearly outside the reef tract as noted previously, the locations of the remaining points were compared to the bathymetry map used for this study, revealing that 99.5% of all points were located within depth ranges previously identified for both species (Table 12). Due to limitations in the bathymetry map used for this study, certain observations were located outside of the mapped area. These points were compared to NOAA nautical charts to estimate depth. Only one observation of *A. palmata* was found outside of the bathymetry map. This point was located offshore of Palm Beach County and estimated to be at a depth of 50 ft (15.2 m). A total of 37 *A. cervicornis* observations were found outside of the bathymetry map. A majority of these (21) were located off Palm Beach County slightly outside the limit of the 60 ft (18 m) bathymetry line. Three points were located approximately 250 m from a 60 ft (18 m) bathymetry line, again off of Palm Beach County. These three points were estimated to be at 90 ft (27 m) using the nautical charts. One observation was located in the upper Florida Keys National Marine Sanctuary on the outskirts of the mapped bathymetry at approximately 75 ft (21 m). One observation in the Dry Tortugas was again located right off the 60 ft (18 m) bathymetry line. The final eight points were the previously discussed CREMP survey observations, which are located between two 60 ft bathymetry lines and within a 100 ft (30 m) line. Therefore, all observations were found within previously determined depth limits of the species.

Table 12: Points in different bathymetric regions. **denotes observations outside of bathymetry map**

Depth Range (ft)	*A. cervicornis*	*A. palmata*
0-3 (0 – 0.9 m)	61	213
3-6 (0.9 – 1.8 m)	530	355
6-12 (1.8 – 3.7 m)	1,029	2,065
12-18 (3.7 – 5.5 m)	532	1,743
18-30 (5.5 – 9.1 m)	429	671
30-60 (9.1 – 18.3 m)	165	0
60-100 (18.3 – 30.5 m)	0	0
50-90 ft (15.2 – 27 m)	1	37

Generation of Probable Habitat Maps

Multiple probable habitat maps were generated. Probable habitat was determined for each species individually, as well as for both species combined. Probable habitat was also generated at two levels, 95% and 99%, therefore, a total of six probable habitat maps were created. Probable habitat was determined based on the buffer distance where 95% and 99% of observations were included, as well as the results of the K-S test.

Across the entire reef tract, a buffer distance of 48 m included 95% of all *A. cervicornis* observations, and a distance of 106 m included 99%. The results of the K-S test suggest that the only significantly different region is southeast Florida; therefore, a different buffer distance was used for this region. In southeast Florida, 95% of *A. cervicornis* observations are included at a buffer distance of 0 m and 99% of observations are included at a buffer distance of 20 m, therefore, no buffer was used for the 95%. The resulting 95% *A. cervicornis* probable habitat is a combination of the mapped reef and hardbottom, without a buffer in southeast Florida with the mapped reef and hardbottom in the Keys and Dry Tortugas having a 48 m buffer. Similarly, the 99% *A. cervicornis* probable habitat map is a combination of the mapped reef and hardbottom with a 20 m buffer in southeast Florida with the mapped reef and hardbottom in the Keys and Dry Tortugas with a 106 m buffer.

Both 95% and 99% of all *A. palmata* observations were included within the mapped reef and hardbottom and therefore no buffer distance was required. The results of the K-S test suggest that no region is significantly different from the entire reef tract in terms of *A. palmata* distributions. Based on these results, the *A. palmata* 95% and 99% probable habitats are a combination of the mapped reef and hardbottom without a buffer from Palm Beach County through the Dry Tortugas.

Across the entire reef tract, a distance of 5 m included 95% of all *Acropora* spp. observations, and a distance of 56 m included 99%. The results of the K-S test suggest that the only significantly different region is the Dry Tortugas; therefore, a different buffer distance was used for this region. In the Dry Tortugas, 95% of *Acropora* spp. observations are included at a buffer distance of 9 m and 99% of observations are included at a buffer distance of 26 m. The resulting 95% *Acropora* spp. probable habitat is a combination of the mapped reef and hardbottom with a 9 m buffer in the Dry Tortugas with the mapped reef and hardbottom in the Keys and southeast Florida with a 5 m buffer (Figure 16). Similarly, the 99% *Acropora* spp. probable habitat is a combination of the mapped reef and hardbottom with a 26 m buffer in the Dry Tortugas with the mapped reef and hardbottom in the Keys and southeast Florida with a 56 m buffer (Figures 17,18). While there are regions in the backcountry of the Florida

Keys (Florida Bay) that are mapped as hardbottom, these areas were excluded from all probable habitat maps as no observations were recorded in this area. All maps were designed to be used with GIS software. As such, the differences between the example habitat maps are difficult to distinguish in the printed format, however are identifiable upon close examination using GIS software.

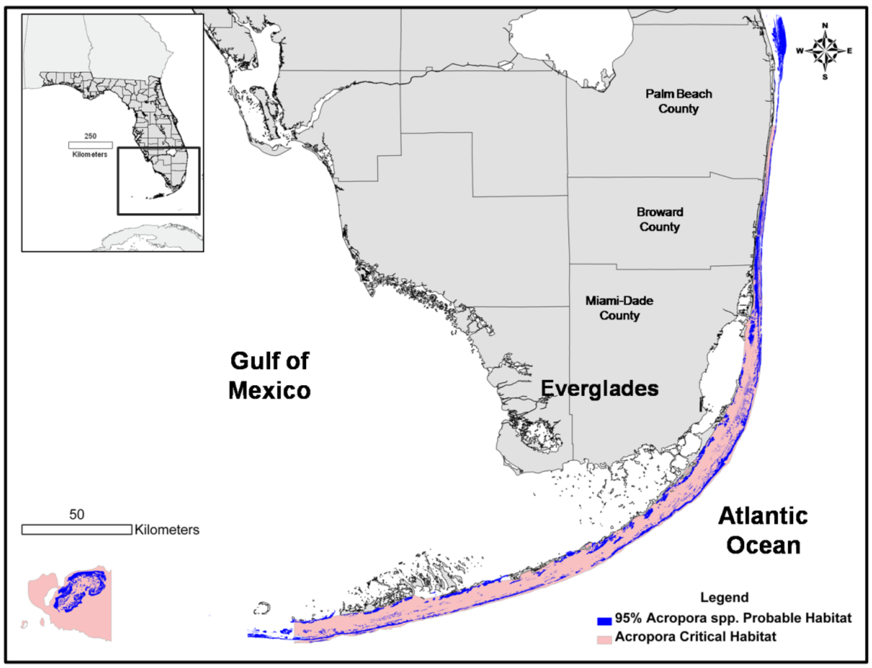


Figure 16: Example of *Acropora* spp. probable habitat generated by this study. This version encompasses 95% of *Acropora* spp. observations.

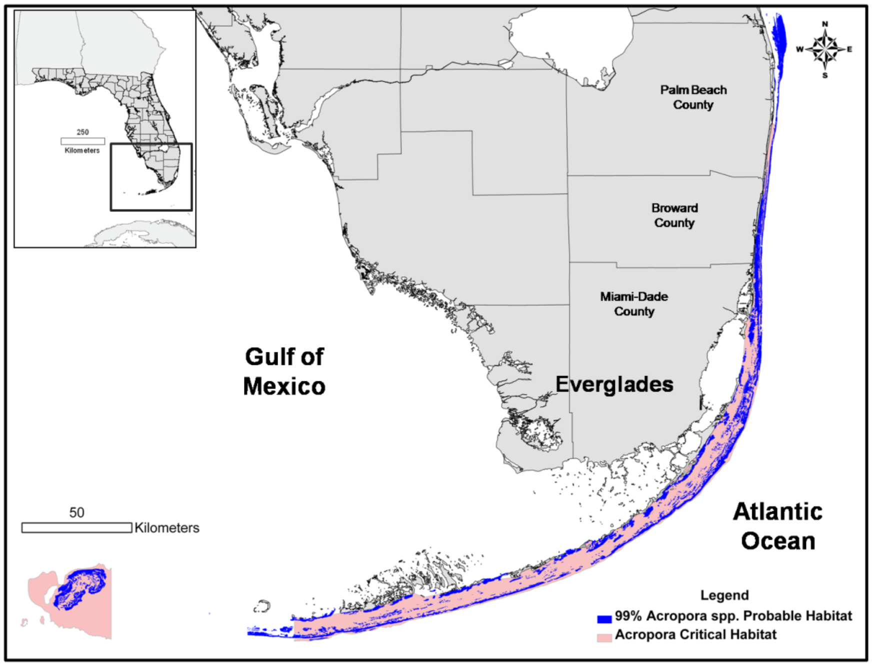


Figure 17: Example of *Acropora* spp. probable habitat generated by this study. This version encompasses 99% of *Acropora* spp. observations.

The Dry Tortugas region has a few unique characteristics. While the distributions based on the new habitat map were still not significantly different when compared to distributions along the entire reef tract, the new map appears to have mapped the reef and hardbottom more accurately. However, the problem with the new map lies in the spatial extent as stated previously. For this reason, the new Dry Tortugas habitat map was combined with the old Dry Tortugas habitat map in order to cover the widest and most accurate spatial extent possible (Figure 19). The area within Dry Tortugas National Park from the 2008 habitat map was combined with the area outside of DTNP from the 1998 habitat map. The various buffer sizes were added to a combination of the new habitat map with the old habitat map to generate the probable habitats in this region.

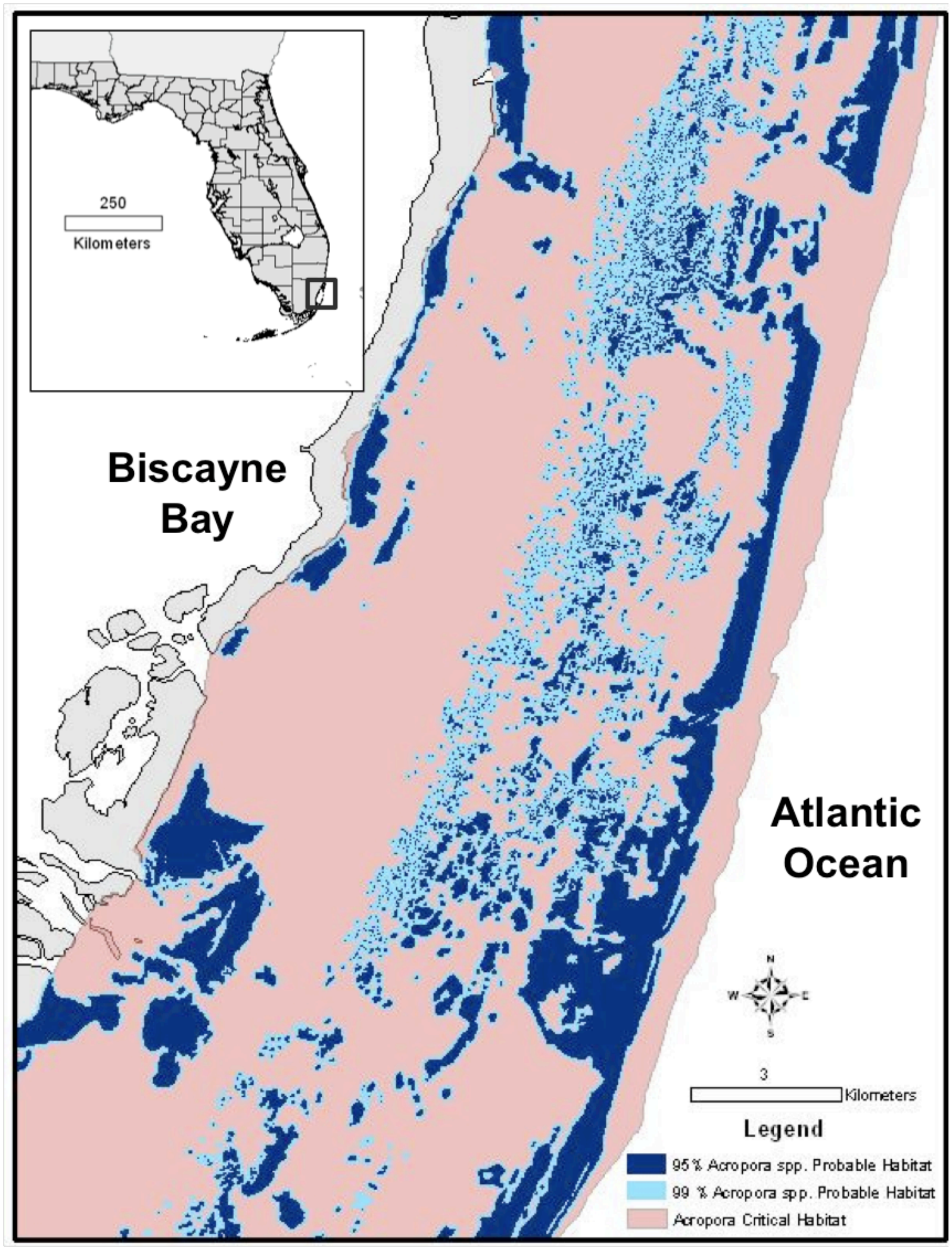


Figure 18: Zoomed in comparison between 95% and 99% *Acropora* spp. probable habitats generated by this study.

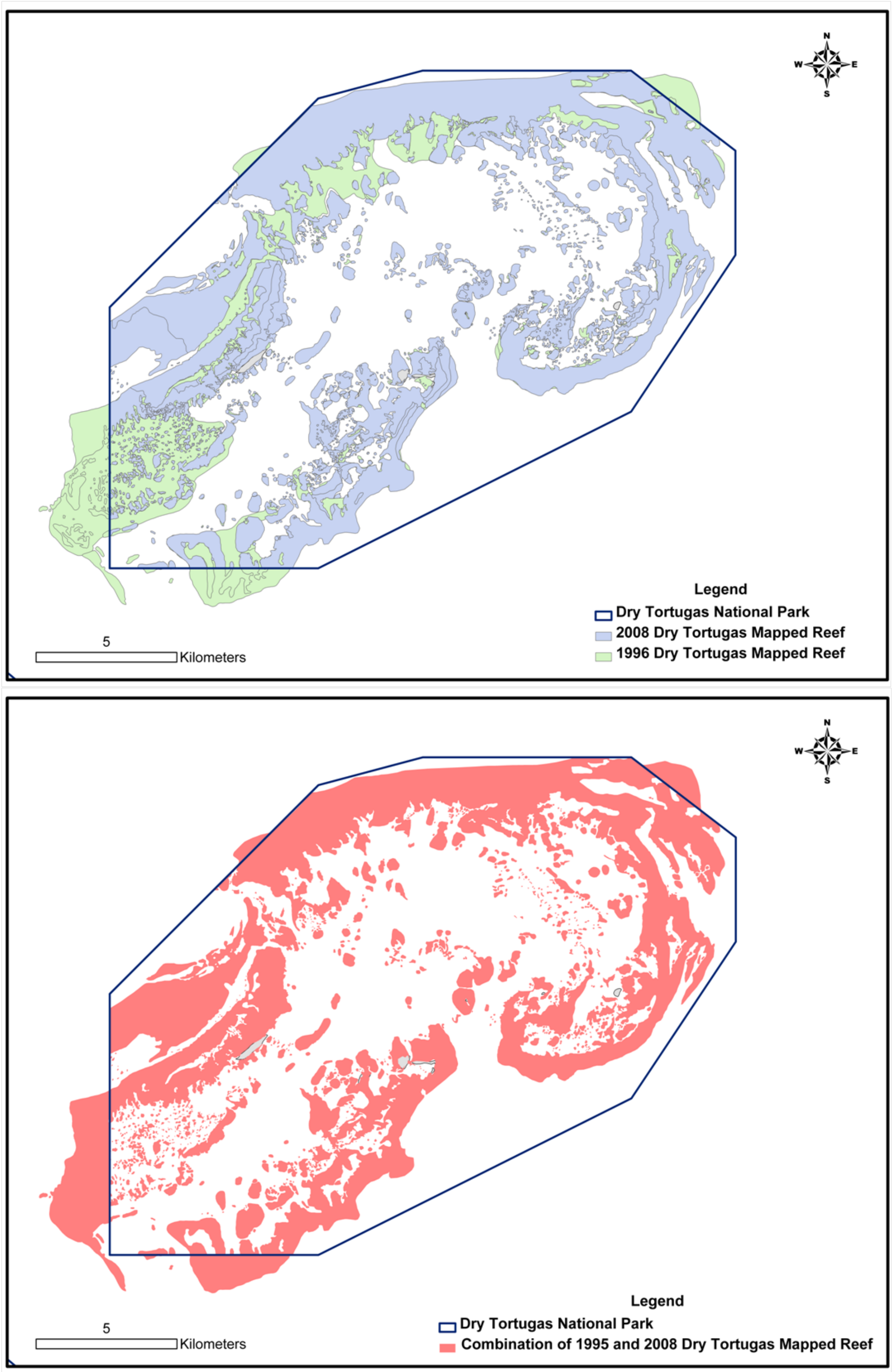


Figure 19: Mapped coral-reef and hardbottom in the Dry Tortugas: a) comparison of the 1995 Dry Tortugas habitat map to the 2008 Dry Tortugas habitat map; b) result of the combination of the 1995 and 2008 Dry Tortugas habitat maps.

DISCUSSION

This study is one of the first to use mapped benthic habitats in combination with an extensive inter-agency database to determine habitat range of *Acropora* spp., throughout the entire Florida reef tract. The results of this study provide the first steps in locating the extent of specific habitat required by *Acropora palmata* and *A. cervicornis* throughout the Florida reef tract and will influence the refinement of the current critical habitat, in order to better represent the habitat which is truly critical to the reestablishment of these species.

Observations incorporated into the database were not spatially uniform. Most observations were recorded from the Keys region and very few from the Dry Tortugas. The lack of observations in the Dry Tortugas is most likely due to the reduced number of surveys taking place in the semi-isolated region of the Florida reef tract each year. There is also the possibility of reduced *Acropora* populations in this region, as the Dry Tortugas have historically experienced disturbances observed to significantly reduce those populations (Mayer 1903; Davis 1982; Jaap 1998; Miller 2003).

Observations of *A. palmata* and *A. cervicornis* were also unequal across all regions, with more observations of *A. palmata* in the Keys region and more *A. cervicornis* observations in the southeast Florida region. The abundance of *A. palmata* observations in the Keys could be attributed to the types of habitat surveyed. A study by Miller et al. (2008) estimated 13.8 ± 12.0 million *A. cervicornis* colonies in the Florida Keys, with 90% occurring on patch reefs, and 1.6 ± 1.4 million *A. palmata* colonies in the Florida Keys, with 80% occurring on high-relief spur and groove reefs. The disconnect between these population estimates and the number of colonies reported to the database is likely the result of a concentration of surveys on the spur and groove reefs, as opposed to the less commonly surveyed patch reefs widely abundant throughout the Florida Keys. The lack of *A. palmata* observations in the Dry Tortugas could be linked to historical disturbance events, which severely impacted and nearly eliminated many of the Dry Tortugas *A. palmata* populations (Davis 1982; Porter et al. 1982; Jaap et al. 1989).

In an ideal scenario, all observations of *Acropora* spp. presence would be located on previously mapped reef or hardbottom. I found approximately 7% of observations outside of these bottom types. However, the majority of these points (270) were of *A. cervicornis* (16% of the observations) compared to only 40 points of *A. palmata* (~1%), which reflects more extensive potential habitat for *A. cervicornis*. The data set also indicates that the habitat for *A. palmata* is much better defined and more limited to reef margins. A multitude of other factors including, but not limited to, map resolution and data-recording errors could also be responsible for the data points that are outside previously mapped reef or hardbottom.

One likely reason for observations located outside of previously mapped reef or hardbottom is the resolution of the benthic habitat maps. A small patch reef with an area smaller than the minimum mapping unit would not be distinguished from the surrounding habitat. For example, a very small patch reef surrounded by seagrass would be categorized as ‘seagrass’. This scenario is particularly likely for areas of thin sediment cover where hardbottom occurs intermittently both spatially and temporally within the seagrass. Another possibility would be an error in the categorization of the habitat type, with areas of hardbottom being mistakenly categorized as ‘seagrass’ or some other type of substrate. Finally, the resolution of the habitat map can be a factor, which I have addressed by providing buffer distances on my probable habitat maps.

Another possibility is habitats have changed since the maps were created. Recent south Florida hurricanes, such as Georges, Irene, Frances, Katrina and Wilma, had the potential to alter habitat. These hurricanes can dislodge and move hard substrate (Geister 1980) and expose hardbottom, creating possible habitat in previously uninhabitable regions. This problem can only be resolved by more frequent mapping efforts, especially after times of high storm activity.

The current database is a compilation of reported observances from many different groups, agencies and individuals. Any number of errors could occur in the data including errors recording latitude and longitude and simple data mix-ups. If erroneous reports were not obviously incorrect, such as the points which were removed in this study, they will remain in the database as observations possibly located outside of reef or hardbottom. Another problem, which would only be applicable for a limited number of points, would be a potential error by the observer. There is the possibility that an individual identifying the species, such as a recreational diver, may not be familiar enough with the species and incorrectly identify it. These identification errors, while possible, would have little influence on the results of this study, as recreational diver observations make up a very small percentage of observations and most data come from reef specialists unlikely to make such errors. What is more likely would be an error associated with the data record. However, since 99% of the *A. palmata* records did fall on previously mapped reef or hardbottom, this indicates that the data set is highly reliable.

As for the significant number of *Acropora cervicornis* reports that really do occur outside of previously mapped reef or hardbottom, this likely reflects the greater range of habitats available to this species. Larvae can recruit in habitats dominated by sand or seagrass as long as there is hard substrate upon which to settle, such as a shell or small outcropping of hardbottom. A brief ground-truthing survey off Key Largo, FL, was conducted in April 2011 to determine if any of the observations outside of mapped reef or hardbottom could be found on sand or seagrass. The results from the few sites examined indicate issues associated with the habitat map. One site in particular, located near Dry Rocks Reef, was mapped as ‘continuous seagrass’ and included multiple observations of *A. cervicornis*. Visual surveys at this location found thickets of dead *A. cervicornis* within a small patch reef dominated by gorgonians. This anomaly was likely due to the minimum mapping unit of the habitat map. This particular patch reef was smaller in size and most likely not detectable by the benthic habitat map and therefore mapped as the surrounding substrate, in this case seagrass.

More extensive surveys are required in the future to examine more sites where discrepancies between mapped habitat and observations occur. The results of such surveys can provide recommendations as to whether it is feasible to better define potential habitat for *A. cervicornis*. However, because 99% of the reported observations of *A. cervicornis* occur within 110 m of previously mapped reef or hardbottom already, mapping effort might be better expended on areas that are currently unmapped, such as much of the Dry Tortugas.

This study confirms that *A. cervicornis* has a wider habitat range than *A. palmata*. This difference is especially apparent in the southeast Florida region, where *A. cervicornis* appears to be thriving outside of mapped reef areas and at latitudes considered marginal for hermatypic corals. This documentation of a wider range of habitat for *A. cervicornis* than *A. palmata* indicates that different management strategies may be required for the two species.

At the time of listing of the species, NOAA designated critical habitat maps throughout the species range within U.S. territory. The newly generated probable habitat maps were compared to the previously determined critical habitat. One interesting aspect of the new probable habitat maps lies in the southeast Florida region. The previously determined critical habitat begins in the southern portion of Palm Beach County, whereas all versions of the new probable habitat maps begin further north, in the southern portion of Martin County (Figure 20). Thirteen *A. cervicornis* observations coincide with reef and hardbottom in the area north of the previously determined critical habitat map. All 13 of these points are located south of 26.682° latitude (as indicated by red line on Figure 20). Figure 20 also shows probable habitat defined by this project north of the northernmost *in situ* data point. The caveat associated with this extended region is that it is solely defined based on the presence of mapped coral reef and hardbottom. At this time, the northernmost extent of *Acropora* spp. is unknown, however this region exhibits areas of reef and hardbottom available for *Acropora* spp. settlement.

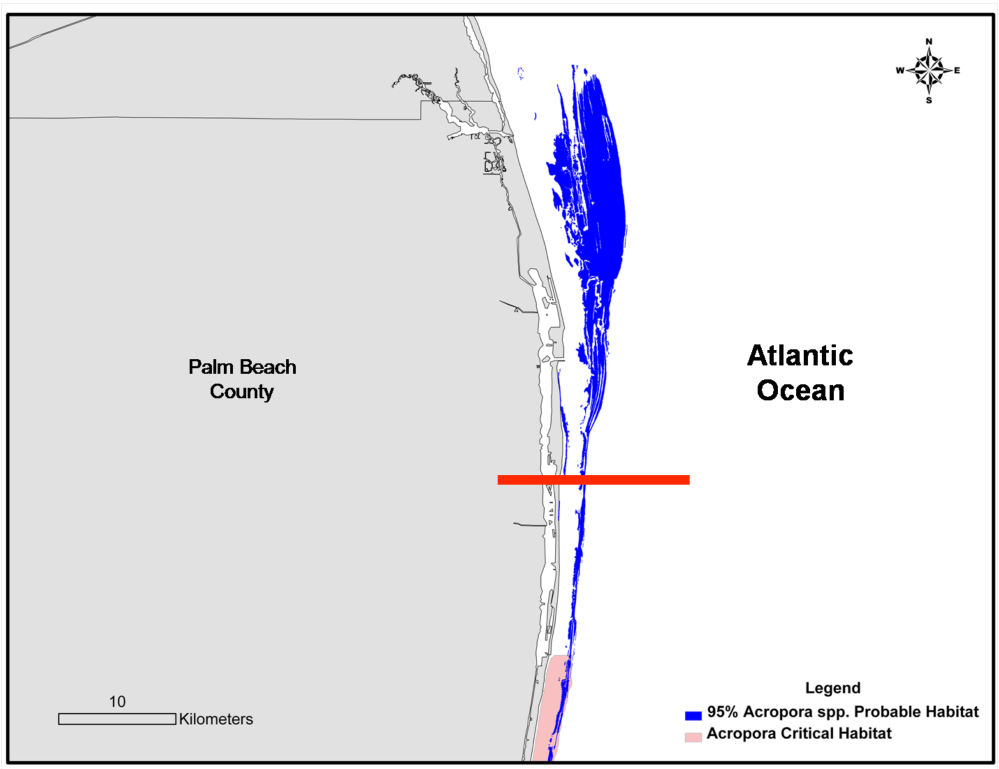


Figure 20: 95% *Acropora* spp. probable and critical habitats off Palm Beach County. The newly generated probable habitat extends further north than the previously determined *Acropora* spp. critical habitat as designated by NOAA at the time of listing as threatened of these species. Solid red line indicates northernmost extent of *in situ Acropora* spp. observations

Probable habitat in the Dry Tortugas region only reaches the extent of the currently mapped reef and hardbottom in the region. The previously generated critical habitat extends further outside of Dry Tortugas National Park and, therefore, encompasses regions that are believed to also be *Acropora* spp. habitat, such as the previously discussed CREMP site (Figure 21). Unfortunately, the current probable habitat map does not include these regions due to the limited extent of the currently mapped reef and hardbottom in the region.

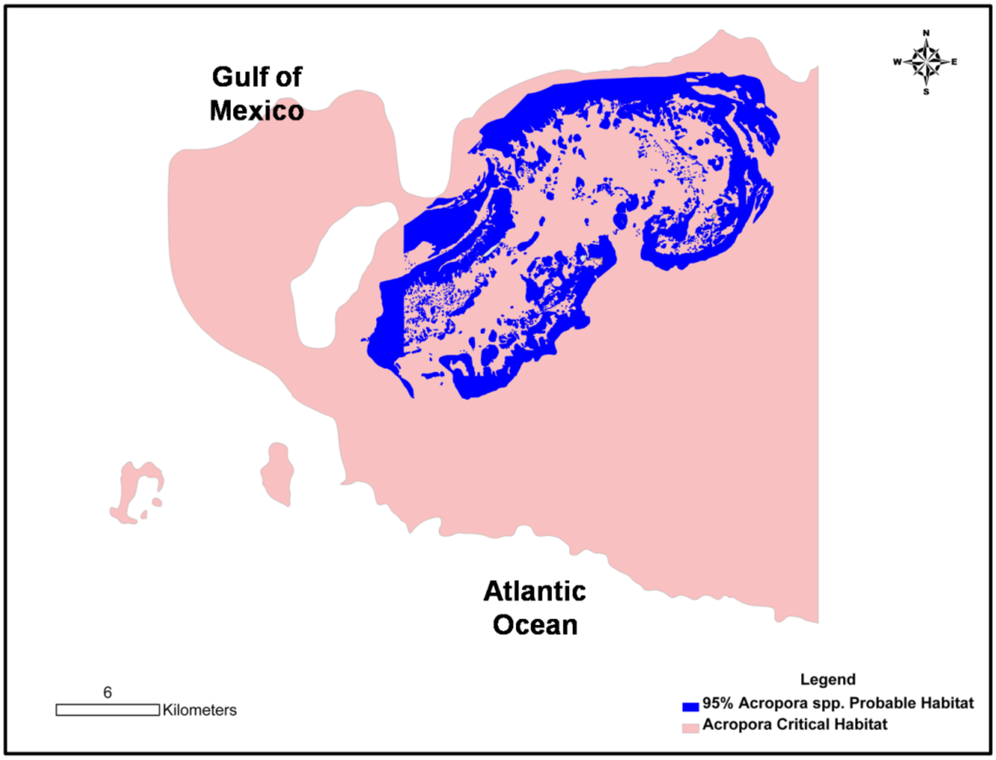


Figure 21: 95% *Acropora* spp. probable and critical habitats around the Dry Tortugas

While this study was examining habitat types of *A. cervicornis* and *A. palmata* throughout Florida, interesting results were revealed in terms of the various habitat maps, which have been produced in these regions. By comparing the old habitat map in the Dry Tortugas to the more recent habitat map in this region, it was obvious that the new map, derived from IKONOS imagery, was more accurate at mapping the regions of reef or hardbottom. This identifies a need for better mapping throughout the Keys, using sensors such as IKONOS imagery, in order to more accurately determine probable habitat for these species of coral. Not only is higher quality mapping needed throughout coral reef areas, but more extensive mapping is also required. One shortcoming of the probable habitat map produced in this study is in terms of the spatial extent, especially in the Dry Tortugas. Several observations in this area are located far outside the mapped reef and hardbottom. By extending the mapping to include these areas, more accurate probable and critical habitats can be determined. Until these areas are mapped, probable habitat can only be speculated from reported observations and not identified to the fullest extent.

Multiple probable habitat maps were produced from the results of this study. Different probable habitats will be useful for various management efforts, and the decision on which probable habitat maps to use will be made by resource management. In general, the 95% *Acropora* spp. probable habitat map may be the best-suited map for general purposes, as its boundaries were determined based on the presence of both species. However, the 99% *A. cervicornis* probable habitat could be used in a situation where the maximum area of potential habitat is desired, given the wider range of *A. cervicornis* as compared to *A. palmata.* Alternatively, the species maps can be used individually, recognizing the quite different environmental requirements of the two species relative to light limitations and water motion.

Possibilities for Future Research

The potential for future work related to this study is extensive. The first step could be to use the same methods from this study to determine habitat of observations from more recent and higher quality habitat maps, when they become available. Areas of the habitat maps, which were categorized as unmappable or uninterpretable, will need to be further examined to determine if probable habitat exists in these areas. The study also needs to be expanded to include the U.S. Virgin Islands and Puerto Rico, where the current critical habitat also needs refinement.

Determining the benthic habitat required of these species is only the first step in determining true “critical habitat.” Other factors, such as water transparency, water quality, and wave action, are also important parameters in determining areas suitable habitat for the reestablishment of the species. The next step will be to incorporate these parameters with the current potential habitat maps to more specifically identify critical habitat for the only species of coral currently on the U.S. Endangered Species List. The resulting potential and critical habitats, from this and future studies, can be used to model loss of carbonate production and fish habitat associated with the decline of these coral species, comparing historical populations to present day populations. The results of this and future studies also have the potential to provide an example of how to determine critical habitat for other coral species in the future.

CONCLUSIONS

1. After editing for obviously anomalous data (i.e., coordinates corresponding to land or deep water), locations of 99% of the observations for *Acropora palmata* coincided with previously mapped reef or hardbottom habitat. This result indicates that potential habitat for this species is currently relatively well defined.
2. After editing as above, locations of 83% of *A. cervicornis* observations coincided with previously mapped reef or hardbottom habitat. An additional 12% of the observations occurred in ‘seagrass’ and 1% occurred in ‘unmapped’ regions. Overall, 93% of the observations occurred within 120 m of previously mapped reef or hardbottom habitat. This result indicates that potential habitat for this species is different and more variable than that for *A. palmata.*
3. This study demonstrated that additional studies of *Acropora* spp., both with respect to occurrence and quality of maps, is needed for the southeast coast of Florida and especially in the Dry Tortugas region.
4. This study provides the new critical habitat delineation for *Acropora* spp. in Florida. Using the mapped reef and hardbottom throughout the Florida reef tract, probable habitat maps were generated, using buffers that

incorporated 95% and 99% of reported observations of colonies of *Acropora* spp.

5. When compared to bathymetry maps, all reported observations of both species were located within reasonable depth limits.
6. One of the most important differences between the previously generated critical habitat map and the new probable habitat map is observed in the southeast Florida region, where probable habitat extends further north than critical habitat and thus encompasses additional important habitat for *A. cervicornis* and potentially *A. palmata*.
7. The previously determined *Acropora* spp. critical habitat map was entirely inclusive of the probable habitat map generated in this study, with the exception of the northern region off of Palm Beach County.

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